Simulation of Streamflow, Lake, and Wetland Water-Surface Elevations in the Swamp and Pickerel Creek Watersheds in the Wolf River Watershed, Near the Proposed Crandon Mine, Wisconsin

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Abstract

The Hydrological Simulation Program - FORTRAN (HSPF) model Version 12 was used to simulate surface water conditions in the 36,172-acre Swamp Creek watershed, and the adjoining 9,423-acre Pickerel Creek watershed in northern Wisconsin. Together these watersheds comprise the study area that may be affected by a proposed underground zinc-copper mine. Potential changes to the surface-water balance may result from changes at the surface due to mine facilities and dewatering of the mine and subsequent water table drawdown. The model was calibrated using streamflow data collected from 1982-1986 at two locations on Swamp Creek above and below Rice Lake, yielding a correlation coefficient of 0.8828 and 0.8394, respectively, and model-fit efficiency of 0.6067 and 0.4447 for monthly flows. The overall water balance was achieved with - 0.1% error above Rice Lake, and 2.4% error below Rice Lake when comparing simulated results to observed data. Other statistical goals related to storms, low flows, and high flows were within the error criteria established in the Quality Assurance Project Plan (QAPP) and data quality objectives. Temporal verification used data from 1978-1981, and spatial verification was provided by simulation of lake water-surface elevations in the adjacent Pickerel Creek watershed. The correlation coefficient for verification above and below Rice Lake was 0.8229 and 0.8346, respectively, and model-fit efficiency of 0.4351 for monthly flows above Rice Lake (0.6793 when three outlier months were eliminated), 0.4826 model-fit efficiency below Rice Lake. All the other error criteria remained well within the targets except in one case where the error criterion was missed by less than 1%. A simulation baseline representing natural conditions was then established using a 41-year continuous time-series of meteorological data. Using the calibrated parameter set, two scenarios were developed for the Swamp Creek watershed to represent the changes under mining conditions, using two different operational pumping rates for the mine. Two scenarios were developed for the Pickerel Creek watershed, using the same two operational pumping rates. The resultant alteration to surface waters ranged from negligible to considerable and include changes in lake stages, lake outflows, stream discharges, flow durations, and wetland water levels. Overall, model results show that the Swamp Creek watershed is less affected by the mine due to the installation of a Soil Absorption System to put water back into the watershed. The model indicates that greater impacts will result in the Pickerel Creek watershed at locations closest to the mine. The results of the scenarios can be compared to the baseline and statistically analyzed as per bioassessment request, for overall impacts, seasonal changes, and different time intervals varying from hourly, daily, monthly, and seasonal, to annual requests. HSPF outputs can be used by bioassessors to determine impacts to biota.

INTRODUCTION

The Nicolet Minerals Company (NMC) has proposed a zinc and copper mine just south of Crandon in northern Wisconsin (Figure 1). The company currently is in the permitting process with the Wisconsin Department of Natural Resources (WDNR) and has submitted an Environmental Impact Report (EIR) to the WDNR and the U.S. Army Corps of Engineers (COE). Because the proposed location of the mine will alter or impact nearby wetlands, federal permits are required as well as state permits. The WDNR and the COE will produce separate and independent Environmental Impact Statements (EISs). As a reviewing agency for the EIR and subsequent state and federal EISs, the U.S. Environmental Protection Agency (USEPA) has applied the Hydrological Simulation Program - FORTRAN (HSPF) Version 12, a hydrologic model, to qualitatively and quantitatively evaluate the impact of the mine on the surface water resources of the area. In particular, the HSPF model is being run to assist in assessing the impacts of the proposed mine on habitat and plant and animal species near the mine. The model has been used extensively by the U. S. Geological Survey (USGS) and consulting engineering firms to simulate and evaluate watershed management plans, storm-water impacts, and solute transport (Duncker et al., 1995; Duncker and Melching, 1998; Jarrett et al., 1998; Zarriello and Ries, 2000).

This document is the final work product of an Interagency Agreement between the USEPA and the USGS in Wisconsin and Illinois. Through a subcontract, the USGS has acquired the services of AQUA TERRA Consultants (which maintains the HSPF model for the USGS and USEPA), to develop and evaluate this HSPF model for simulation of changes in runoff resulting from mine construction and operation. The HSPF model complements the impact analysis for the water budget done on the basis of the MODFLOW ground water model developed by the NMC as described in NMC's EIR. The WDNR and COE also are in the process of utilizing MODFLOW to evaluate the mining impact on groundwater.

The processes of runoff, snowmelt, evapotranspiration, interception, and interflow, and the changes in these processes due to construction and operation of the mine are not simulated in the groundwater flow models. Simulation of these processes is critical to a more complete understanding of the effects of mining on the environment and to address unique issues potentially impacted by the mine, such as maintaining the viability of wild rice and the wildlife, stream, and wetland habitat which is culturally significant to the four Native American Tribes and other residents located in proximity to the site. Given the potential impacts on such a geologically and hydrologically complex area, the land-surface portion of the hydrologic cycle is simulated with HSPF with an emphasis on the surface waters, the water budget, and fluctuations of the water budget. The changes in runoff and water levels resulting from land cover changes at the mine site and groundwater drainage to the mine as simulated with HSPF will be utilized to evaluate the risk to habitat, including the discharge or water levels that are supporting wild rice habitat. Wild rice is culturally significant to the Mole Lake Band of the Sokaogon Chippewa, and the reservation location was chosen due to the presence of the wild rice at Rice Lake and Mole Lake. HSPF can simulate soil erosion, sediment transport, and pollutant transport within a watershed, but this option was not applied in this study because of the lack of sediment and pollutant load data in the Swamp and Pickerel Creek watersheds needed to calibrate any modeling.

Potential impacts from the proposed Crandon Mine on the watersheds comprising the headwaters of the Wolf River (designated as a State Outstanding Resource Water), and surrounding the project site are of major concern to residents in the area. Residents include four tribes of Native Americans within a few miles of the proposed mine: the Sokaogon Chippewa Community Mole Lake Band, the Forest County Potawatomi Community, the Menominee Indian Tribe of Wisconsin, and the Stockbridge-Munsee Band of the Mohican Indians. The Sokaogon Chippewa Community Mole Lake Band and Forest County Potawatomi live in close proximity to the mine site in the Swamp Creek watershed, which covers the southern and eastern part of the Upper Wolf River and Post Lake Watershed (Figure 2). The Potawatomi lands are also located in the Peshtigo River Watershed. All parties involved in the permitting of the mine have concerns about the potential environmental impacts, which are being addressed in the EIS process.

Acknowledgments

The authors would like to thank the project team leader at the USEPA, Dan Cozza, whose constant guidance and support was instrumental in keeping the project alive. Thanks to the peer review and recommendations by Dr. Raymond Whittemore and Dr. Gustavius Williams. Initial modeling runs were performed by USEPA intern Troy Naperala. Thanks also are extended to Dr. Alan Lumb for his review of and suggestion on the model calibration and verification procedure and results. Both quality assurance input and encouragement by Joan Karnauskas are greatly appreciated. Thanks to all those who provided field assistance, data, and insight to the complexity and unique qualities of the area, including the Tribes, Great Lakes Indian Fish and Wildlife Commission, and Nicolet Minerals Company. Thanks to Margaret Thielke who built a great team by pulling together all those from AquaTerra Consultants and the USGS in the early phases of the project, and who saw the utility of surface water modeling for EIS bioassessment.

SITE AND PROJECT DESCRIPTION

Two watersheds located within the Wolf River watershed will potentially be impacted by the mine and are examined in this study. The regional location of these watersheds is shown in Figures 1and 3. The Swamp Creek watershed lies north of and directly over a portion of the ore body; it has an area of 36,172 acres (56.5 mi²). The Pickerel Creek watershed is adjacent to and south of Swamp Creek and Rice Lake, it lies over a portion of the ore body, and has an area of 9,423 acres (14.7 mi²). The total area encompasses 45,595 acres (71.2 mi²) and will be referred to as the “study area” (Figure 3).

The proposed mine is in a sulfide ore deposit located approximately 300-350 ft below the land surface. The deposit extends to 2,200 ft beneath the land surface at its deepest point. It is about 300 ft wide, and is nearly 1 mi long. This deposit would be mined primarily for zinc and copper, at a rate of approximately 5,500 tons per day over the course of a 28-year life producing a total of 55 million tons of ore. These minerals were deposited as ocean floor volcanics that were later metamorphosed and tilted to a nearly vertical position. The bedrock is composed of metamorphosed igneous rocks. The surface layers are composed of glacial till and outwash, with a hummocky, forested land surface with many lakes and wetlands. Because of the depth of the proposed mine, about 648,000 gallons per day (gpd) (estimated from the NMC Mine Permit Application (MPA) pumping rate of 450 gpm) of ground water will be pumped from the mine area. The water is then treated and discharged to a Soil Absorption System (SAS) at an average rate of 540,000 gpd, ranging from 96,480 to 915,840 gpd, using NMC’s MPA minimum and maximum pumping rate estimates of 67 gpm to 636 gpm, respectively. The ground water pumpage will result in drawdown of the potentiometric surface or water table, which will affect the watersheds surrounding the mine site. Because all the aquatic resources in the upper Wolf River watershed are designated by the WDNR as fully usable, the potential for any permanent damage to those resources must be considered to be significant because of the rarity of such undeveloped watersheds. The effects from drawdown of the water table due to mine dewatering may be increased or decreased when combined with other site-related activities (such as the clear-cutting of trees for buildings and tailings management, building access roads and rail spur lines, increasing housing and buildings, potentially changing drainage patterns and surface water flows). Proposed mine facilities are shown in Figure 4.

MODEL UTILIZATION FOR BIOLOGICAL ASSESSMENT

The HSPF model is being run to assist in assessing impacts from the project on surface water levels and flows affecting habitat and plant and animal species. The results from this model may be used by biologists for biological impact assessment, as well as by others for formulating mitigation and long-term monitoring plans.

HSPF will only simulate changes in water levels (in lakes and wetlands) and discharge. The simulated long-term (41 years) time series of runoff for natural and mining conditions are summarized as frequency distributions of lake levels, wetland levels, and discharges. These frequency distributions may then be

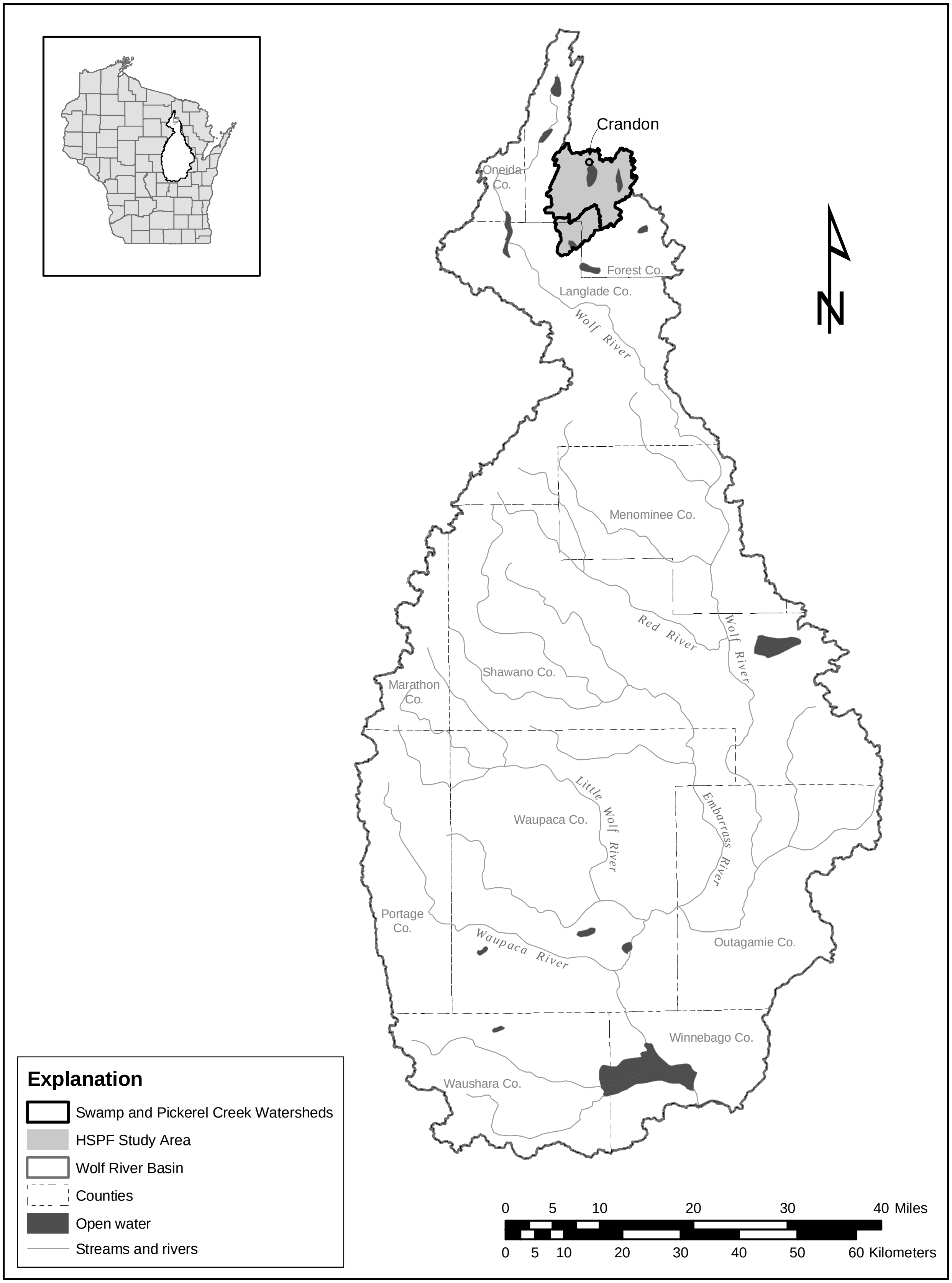


Figure 1. Location of the study area within Wolf River Basin in Forest and Langlade Counties, Wisconsin.

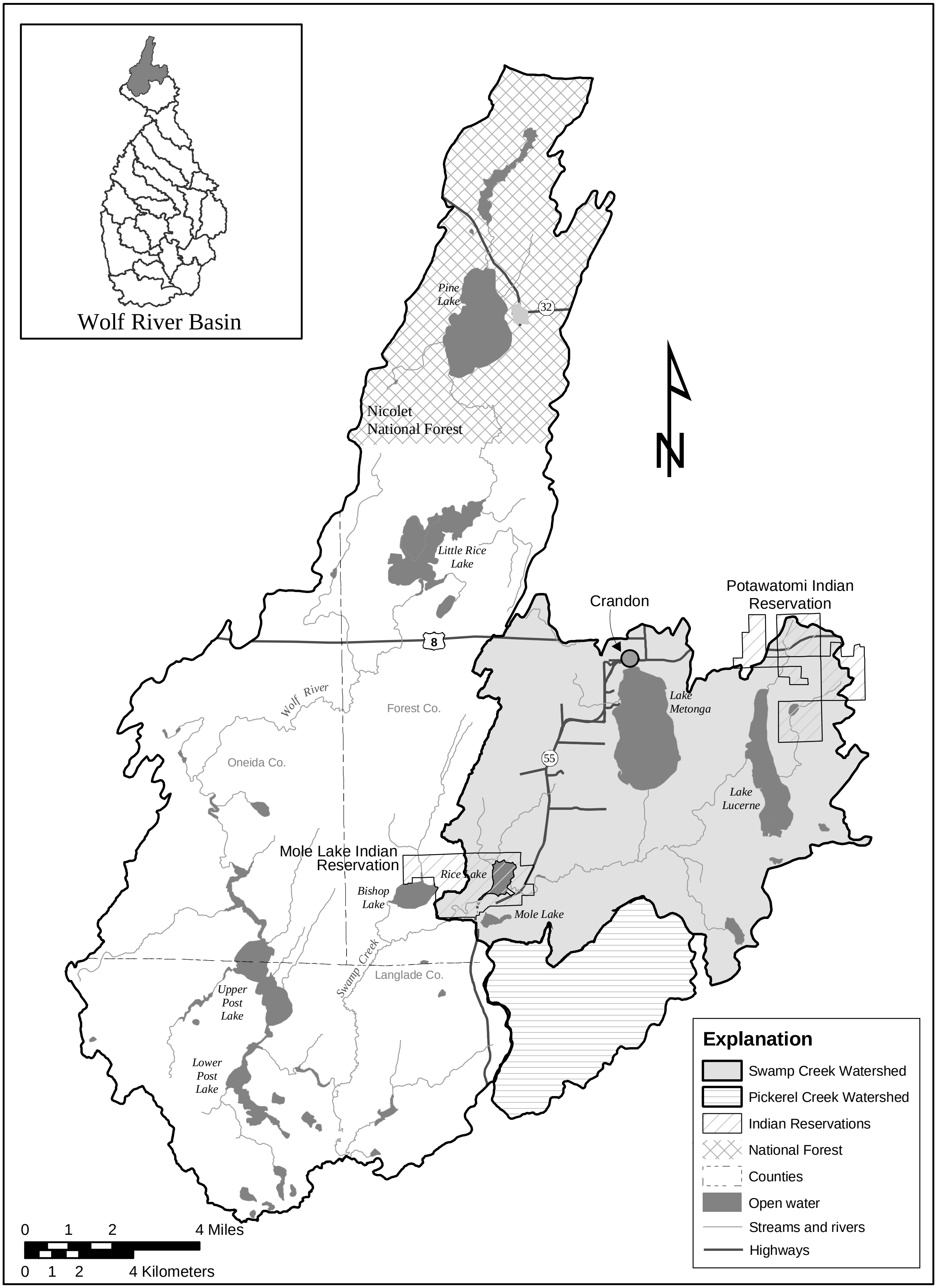


Figure 2. Location of the study area in Upper Wolf River and Post Lake Watersheds.

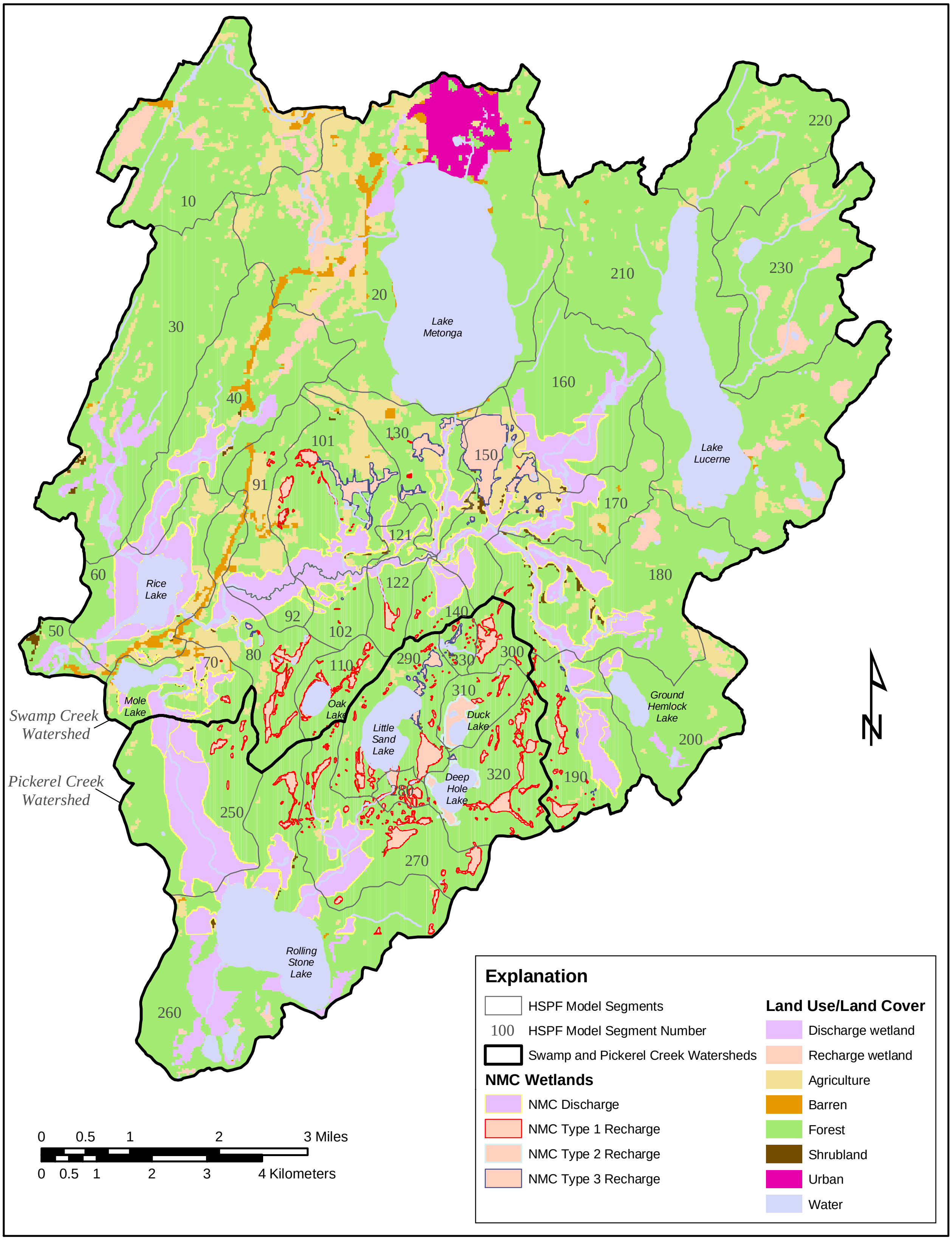


Figure 3. Study area land use/land cover with wetlands and HSPF segments.

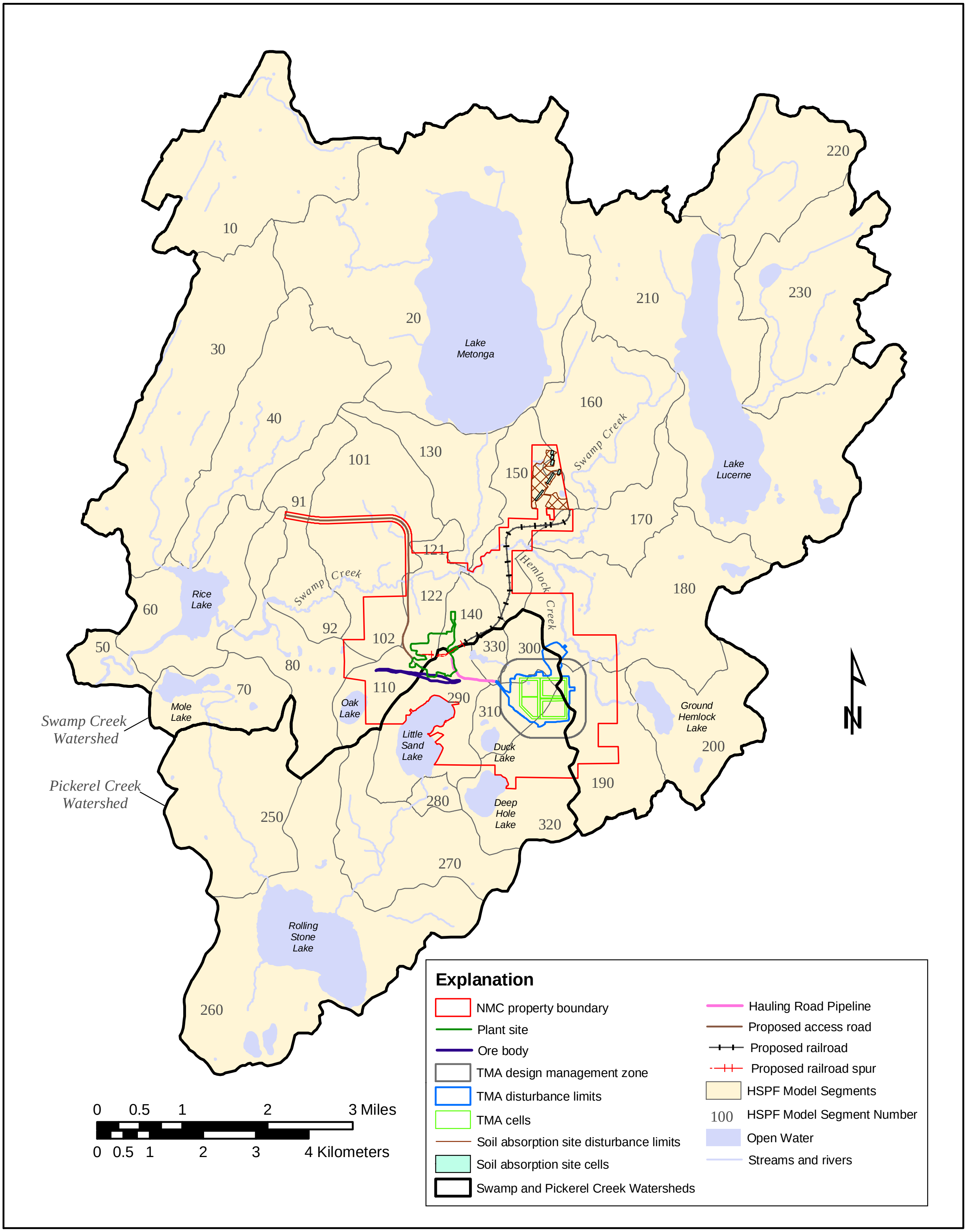


Figure 4. Nicolet Minerals Company property boundary and mine site infrastructure.

analyzed during key times in the life cycle of individual indicator species such as reproductive phases, critical developmental phases, or stress times.

The U.S. Forest Service uses the Management Indicator Species (MIS) evaluation to choose management species for assessment and long-term monitoring. In the MIS, four factors - 1) species background, 2) indicator criteria, 3) significant effects, and 4) socioeconomic impacts - may be considered in the evaluation.

The *species background* is important in selecting management indicators, such as whether it is: Federally-listed as endangered or threatened; Regionally Sensitive; in demand for recreation, commercial, or subsistence use; representative of special habitats; or indicative of trends in other species or conditions of biological communities.

The characteristics used for choosing *indicator criteria* may include some or all of the following taxonomic characteristics, as well as whether the species best represents a public issue, concern, or opportunity. The taxa used for baseline data should be:

- reasonably common, and well distributed within a water body. This will provide some assurance of being able to measure the species in future sampling efforts and allow for statistically significant sample sizes.
- easily identified, and not likely to be confused with other taxonomic entities.
- known or suspected to be sensitive to distinctive environmental changes which are expected as a result of the Crandon Mine project. This helps ensure that there is a high correlation between change in populations and the specific environmental change.
- expected not to exhibit wide fluctuations in abundance, which could make actual population changes difficult to detect.
- having a rapid response to change (e.g., periphyton)
- either well enough understood or sufficiently sensitive that thresholds or triggers can be identified.

The primary *socioeconomic* concerns to the Tribes and many others in the area are the natural resources of rice, fish, and water fowl, and the overall health of the waters and the environment. Many of the Tribal economic, cultural, and ceremonial practices are closely associated with these resources. Though impacts on these resources cannot directly be interpreted in the modeling analysis, the greatest potential impact of the project will more likely be on the culture of two of the four Tribes closest to the project.

DATA COMPILATION

The hydrologic cycle is a conceptual framework that describes the movement of water within a watershed and between land, water bodies (streams, lakes, and wetlands), and the atmosphere. Data collection defines watershed characteristics (such as soils and land cover) and provides measured inputs (precipitation), estimates of internal fluxes (potential evapotranspiration, groundwater recharge, and others), and measured outputs (runoff) necessary for the calibration of a hydrologic simulation model.

Hydrologic Data

Runoff data were collected at two streamflow-gaging stations in Swamp Creek, located immediately upstream and downstream of Rice Lake. Electronic data loggers provided continuous-recording stage data at an hourly interval. Streamflow records for the watersheds are rated as "good" (within 10 percent error) for most of the full period of record, except for estimated periods (such as winter periods when the stream is ice-covered or periods of missing record), which are rated "poor" (within 15 percent error). Runoff from the 46.3 mi^2 portion of the watershed above Rice Lake (USGS gage #04074538) (Figure 5), which includes part of the proposed mine site, was measured at the USGS gage from August 1977 to September 1983 and from October 1984 to December 1986. Runoff from the 56.7 mi^2 portion of the watershed below Rice Lake (USGS gage #04074548) was measured at the USGS gage from August 1977 to September 1979 and from April 1982 to June 1985. Streamflow was estimated for each gage site

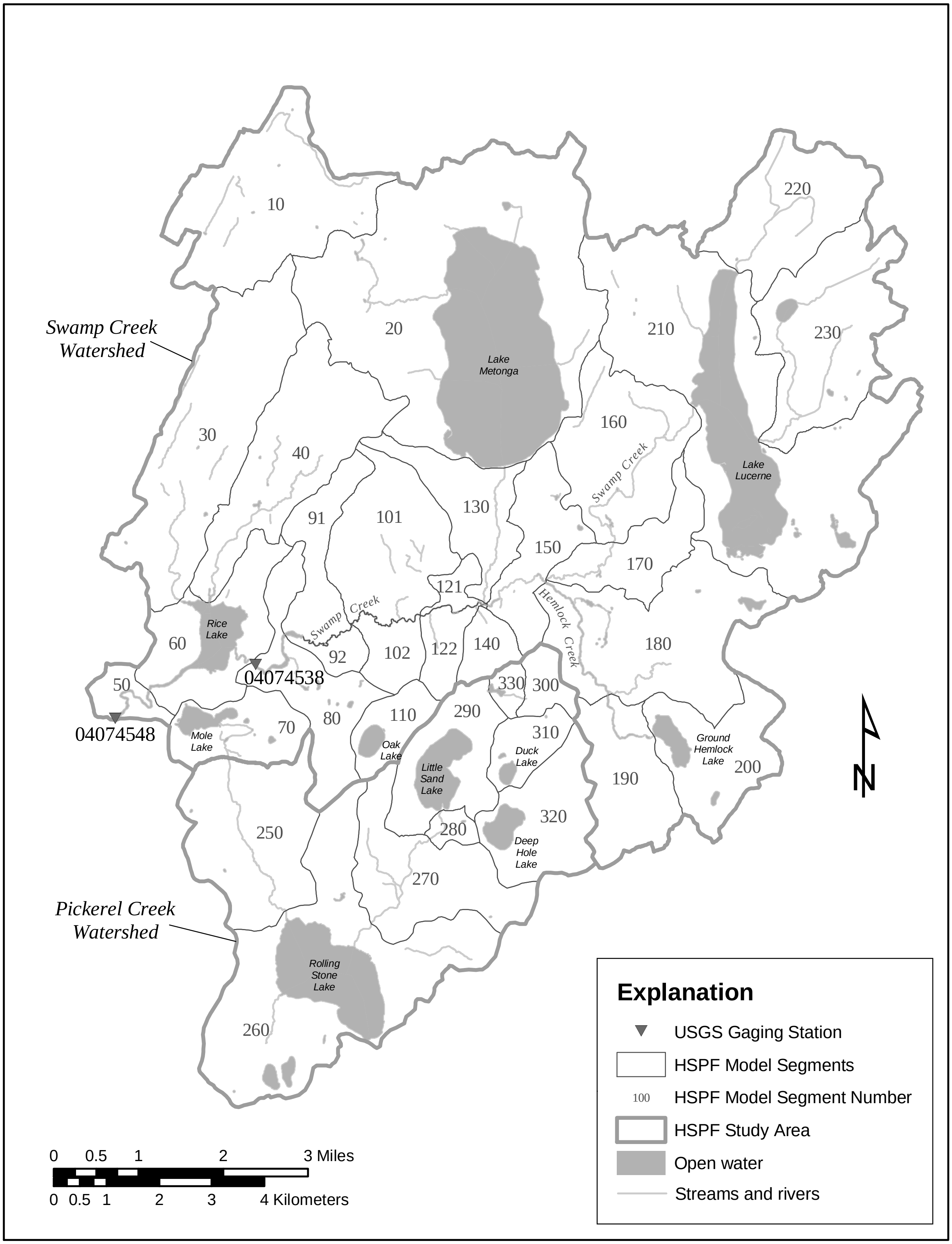


Figure 5. USGS gaging stations and HSPF segmentation.

for the periods when the gage was not operational utilizing the data at the other gage and a value of 1.43 for the ratio of flow below Rice Lake to the flow above. Therefore, runoff data are available for a period of 9 years and 5 months (August 1977 to December 1986) at these gages.

A comparison of the contributing land areas to these two gaging stations suggests an approximate ratio of 1.22 for the flow below to the flow above Rice Lake. However, regression analysis of the measured flows produced a ratio of 1.43, which suggests that additional areas are contributing to the station below Rice Lake and/or some of the watershed areas above the lake are not contributing. Particle tracking analysis of groundwater data and model results, discussed further in “Hydrological Relations” section, strongly supported this hypothesis, and led to contributing land area adjustments in the model.

NMC also made discharge measurements on selected days at 14 locations within the Swamp and Pickerel Creek watersheds between November 1993 and March 1995. These measurements were too infrequent to develop stage-discharge ratings and continuous streamflow data, and they were made outside of the calibration and verification periods (discussed below). They typically were made during low-flow periods at several locations within a few days. Thus, these measurements, even though infrequent, were used to check internal fluxes among subsections in the HSPF model simulation to determine if the areal distribution of simulated runoff is reasonable.

Water-level data for 314 observation wells in the vicinity of the proposed Crandon Mine are available on a monthly basis sporadically from 1977 to 1995. Among these, 23 wells are located in wetlands (Figure 6) and can be used to guide the calibration and verification of the simulation of wetland water levels with HSPF. Lake-level data are sporadically available on a monthly basis from 1977 to 1995 for Deep Hole Lake, Duck Lake, Little Sand Lake, Oak Lake, Rolling Stone Lake, Rice Lake, Skunk Lake, Ground Hemlock Lake, and Hoffman Springs. The data are available from the NMC EIR. Figure 7 shows locations of cross-sections measured in the field to help determine stream channel dimensions for estimation of properties of the FTABLES portion of the model, quantifying characteristics of the lakes and streams.

The meteorological data or estimates required for the hydrologic modeling include precipitation, potential evapotranspiration, snow depth, air temperature, dew-point temperature, wind speed, cloud cover, and net solar radiation (Table 1). Meteorological data were thoroughly analyzed for consistency and completeness prior to model simulation. Reliable data were available from 1955 through 1995, so this time interval was chosen for the baseline simulation. Some visual inspection of plots was utilized to detect gross data anomalies. The data were obtained from the National Weather Service, Midwestern Climate Information Center (MICIS) (Kunkel et al., 1990), and other repositories, and re-formatted as Watershed Data Management (WDM) files. All data re-formatting and processing were done using WDM utility software packages developed by the USGS. These programs include IOWDM (Lumb et al., 1990) for data re-formatting, ANNIE (Flynn et al., 1995) for data summary and display, and METCMP (USGS, unpublished) for data correction and generation.

Precipitation data are the principal input to the watershed model, providing the driving force for the land-surface portion of the hydrologic cycle, including flow in the soil and snow accumulation and melt. Precipitation data are available at 15 stations near the proposed mine (Table 2) as shown on the map in Figure 8. The precipitation data used for the model were developed using the procedure described by COE/Barr Engineering Company (1997), in which inverse-distance weighting was used to develop a single long term rainfall record based on the two nearest stations with good quality records. The details of this procedure are as follows: 1) The daily data recorded at Laona 6 SW and South Pelican Lake were adjusted (i.e., weighted by a factor of 0.88192) using adjusted Summit Lake data. 2) The adjusted data were combined using weighting factors computed from inverse distance factors based on the distance from the station to the TMA; the weighting factors, shown in Table 3, range from 57% to 84% for Laona 6 SW and 16% to 43% for South Pelican Lake, due to the changing location of the Laona 6 SW station. 3) The resulting daily record was disaggregated to a one-hour interval using the hourly pattern at the Three Lakes station, with missing periods in Three Lakes record filled by White Lake or Green Bay Airport data.

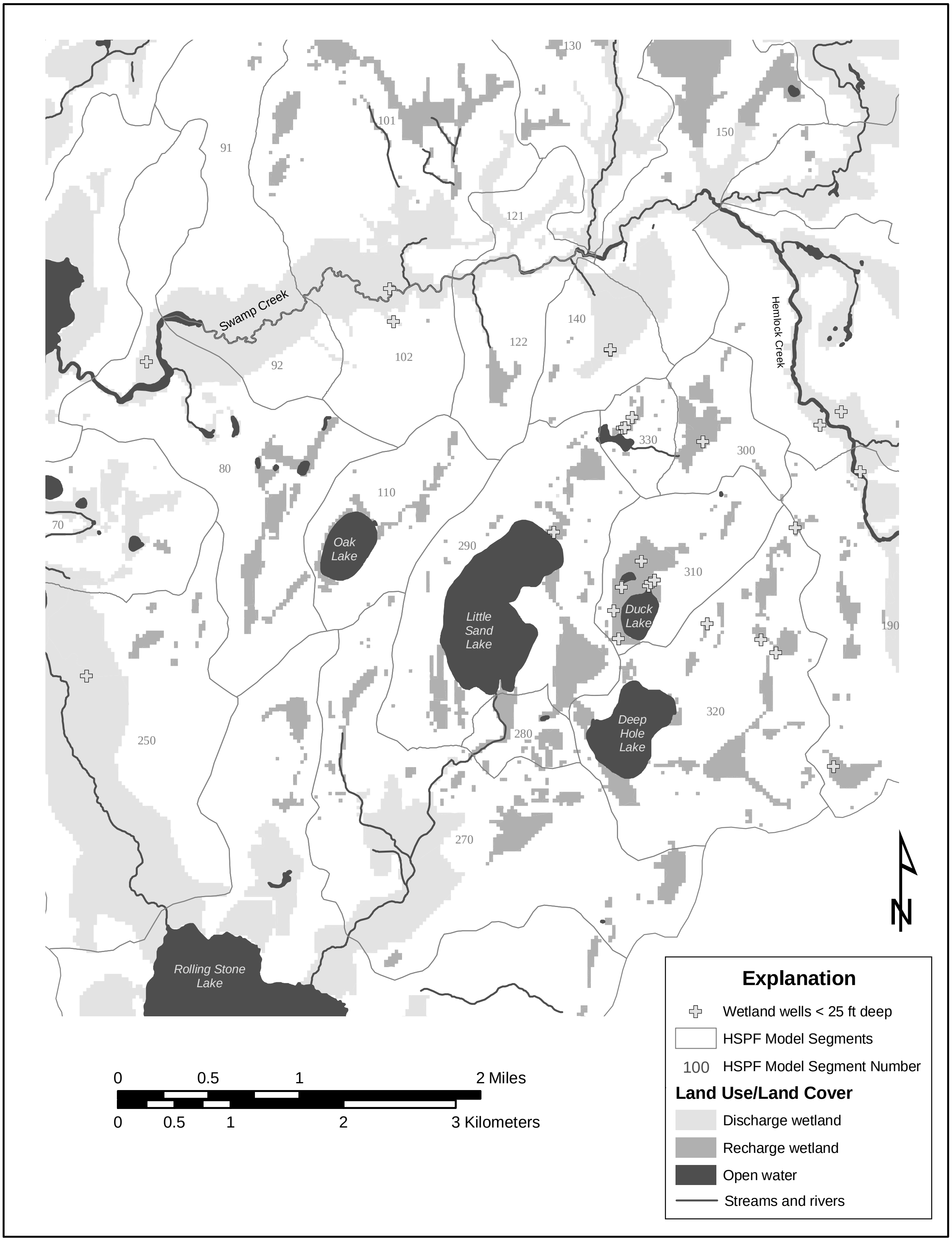


Figure 6. Wetland wells less than 25 feet deep.

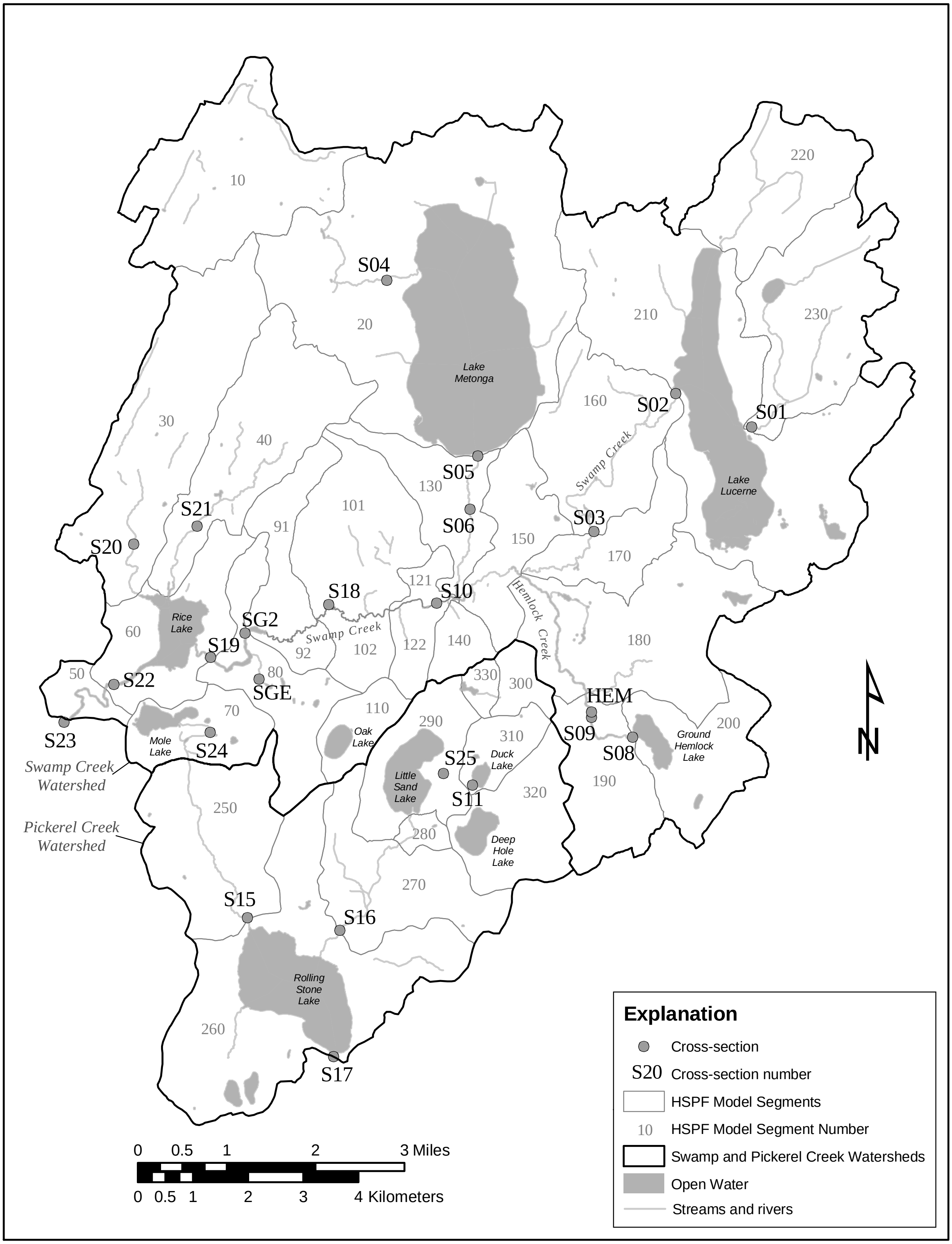


Figure 7. Locations of stream cross-sections used in HSPF model development.

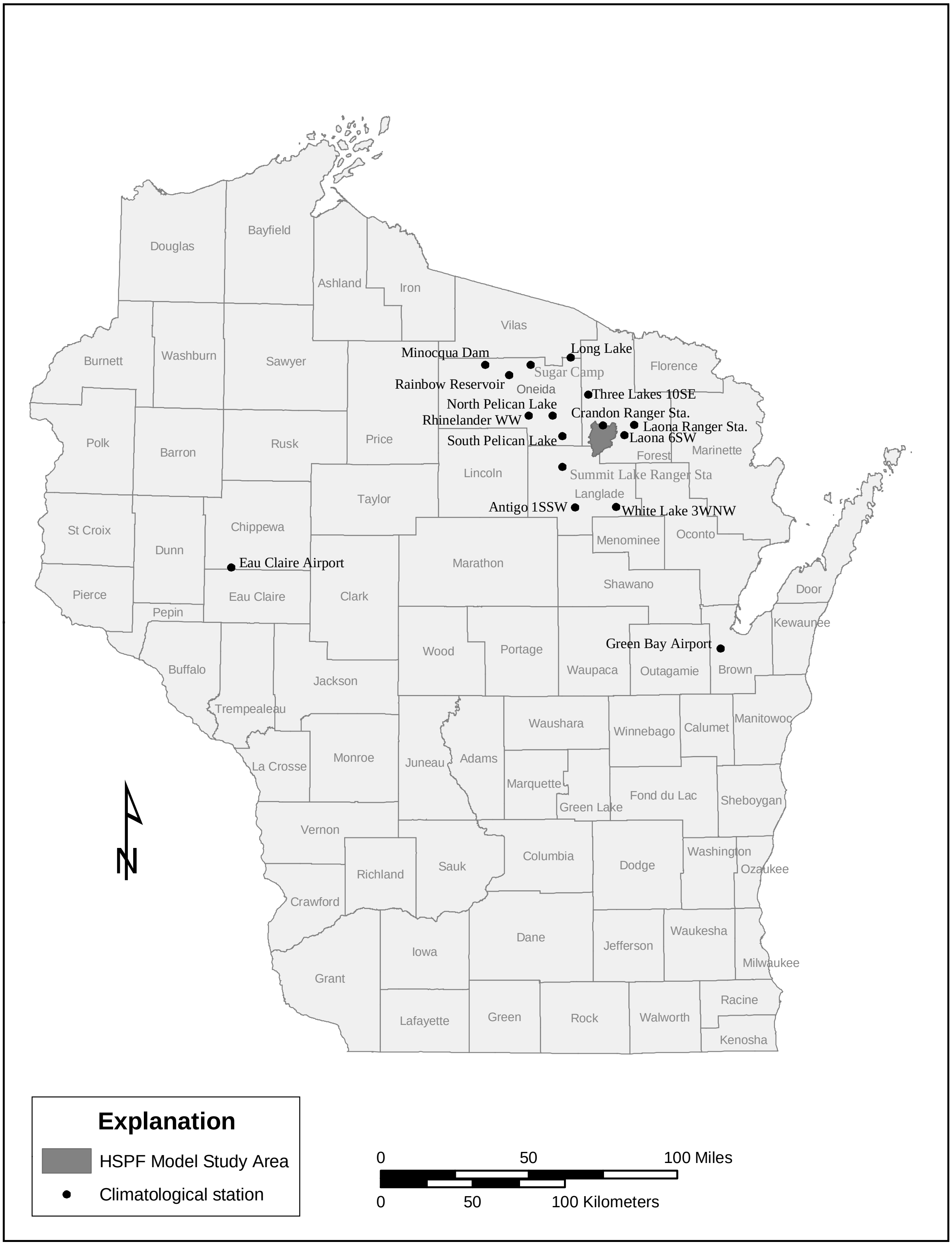


Figure 8. Climatological stations used in this study.

Evaporation estimates are input to the model in the form of potential evapotranspiration (PET) in units of inches per day. The HSPF model computes actual evapotranspiration from each soil zone based on the input PET time series and soil zone-specific evapotranspiration parameters. The PET estimate set used in the modeling was obtained from the Midwestern Climate Information Center (MICIS). The estimates were computed using the Penman-Monteith method (Monteith, 1965) from meteorologic data collected at Green Bay Airport. These data were used instead of pan evaporation data collected at Minocqua Dam, because they were more representative of the long term average annual PET (Environmental Data Service, 1979) in the vicinity of the mine site, and because the period of record of the data set at Minocqua Dam did not support long term simulations.

In addition to rainfall and potential evapotranspiration, five meteorological data series are needed as input for the model. These data series, which are used to drive the snow accumulation/melt sub-routines of the HSPF model, are air temperature, dewpoint temperature, wind movement, cloud cover, and solar radiation. Each of the data types was derived from the nearest station to the study area that collects that type of data and has a sufficient period of record to satisfy the long-term model simulation requirements. Where necessary, other nearby stations were used to fill missing periods in the selected data series. Also, snow depth data at three locations were used for comparison with simulated snow pack depths. Table 4 lists the primary stations that were used to provide the auxiliary meteorologic data.

Air temperature data are used to determine whether precipitation falls as rain or snow, and as a component in the snow pack energy balance. The model adjusts air temperature based on lapse rates and the elevation difference between the station and the mean elevation of the land segment. The data series used in this model was based on the station at Laona (6 SW). Daily maximum-minimum data collected at this station were disaggregated to an hourly interval by application of a diurnal curve to the data with the maximum at 4:00 PM and the minimum at 6:00 AM.

Table 1. Data or estimate type, time resolution needed for model, and units

Data Type	Time Resolution for Model	Units
precipitation	1 hour*	inches
potential evapotranspiration	1 day	inches
air temperature	1 hour	deg F
dewpoint temperature	1 day	deg F
wind movement	1 day	miles per hour
cloud cover	1 day	tenths
solar radiation	1 hour	Langleys
streamflow	1 day	cfs
lake levels	1 month	ft
snow depth	1 day	in, ft
groundwater levels	1 month	ft

* All of the rainfall data used directly in the modeling was collected at a 1 day resolution, and was disaggregated to a 1 hour time step by using some nearby stations that were collected at 1 hour intervals.

Table 2. Climatological Stations considered when developing input for the Hydrological Simulation Program-Fortran model of the Swamp and Pickerel Creek watersheds near Crandon, Wisconsin (na, not available)

Station Name	Time Interval	Precipitation Record	Temperature Record
North Pelican Lake	day	1945-1998	1950-1998
South Pelican Lake	day	1945-1997	na
Summit Lake Ranger Station.	day	1948-1998	na
Three Lakes	day, hour	1944-1997	na
White Lake	day, hour	1932-1998	na
Rainbow Reservoir	day	1947-1996	1948-1996
Minocqua Dam	day	1903-1998	1903-1998
Laona 6 SW	day	1927-1998	1948-1998
Antigo1 SSW	day	1896-1998	1896-1998
Crandon Ranger Station	day	1896-1998	1896-1998
Rhinelander	day	1908-1998	1908-1998
Green Bay Airport	day	1896-1998	1896-1998
Eau Claire Airport	day	1949-1998	1949-1998
Sugar Camp	day	1910-1998	1973-1981
Long Lake	day	1908-1998	1908-1996

Table 3. Weighting of Laona 6 SW and South Pelican Lake Precipitation Data used to simulate runoff from the Swamp and Pickerel Creek watersheds near Crandon, Wisconsin

Date		Laona 6 SW		South Pelican
1/48-9/52	57%		43%	
9/52-4/53	61%		39%	
5/53-5/54	57%		43%	
5/54-7/54	65%		35%	
7/54-10/69		74%		26%
11/69-1/82		84%		16%
1/82-present		80%		20%

Dewpoint temperature also is used in the determination of whether precipitation falls as rain or snow. Since dewpoint temperature data were not available at any nearby stations, the minimum daily temperature data at Laona 6 SW were substituted for the dewpoint data.

Wind speed, in the form of daily total movement, is used to determine evaporation from the snow pack and atmospheric heat exchange with the snow pack. The nearest wind movement/wind speed station is Eau Claire, WI, and missing periods in this data series were filled from the Green Bay Airport station.
Cloud cover data are used to estimate back radiation to the snow pack from clouds, a component of the snow pack energy balance. The data series used in this model is a combination derived from two stations. The data after 1979 were computed directly from "percent clear sky" data at the Minocqua Dam station. The data prior to 1979 were back-calculated from solar radiation data based on conditions at the Eau Claire Airport station. The daily cloud cover data are expressed as tenths of sky cover, i.e., the values range from 0 to 10, where 0 represents clear sky and 10 represents complete cloud cover.

Solar radiation is used as a component in the radiative heat supplied to the snow pack. It generally is input to the model as hourly values, and often is estimated using solar models and meteorologic parameters, such as cloud cover. The data series used in the Swamp Creek/Pickerel Creek model is a combination derived from two stations. The data starting in 1979 were computed from a simple solar model (Hamon et al., 1954) using clear sky/cloud cover data from the Minocqua Dam station. The data prior to 1979 were obtained from MICIS; they were computed using a more detailed solar model (Petersen et al., 1995), and are based on meteorologic data from Eau Claire Airport.

Table 4. Other meteorological data stations used in developing the input for the Hydrological Simulation Program-Fortran model of the Swamp and Pickerel Creek watersheds near Crandon, Wisconsin.

Data Type	Station Name	Period of Record
Air Temperature	Laona 6 SW *	1948-1997
	Minocqua Dam	1905-1997
	Rainbow Reservoir	1948-1996
	North Pelican Lake	1950-1997
	Antigo	1948-1997
	Long Lake	1948-1996
Dewpoint Temperature	Green Bay Airport	1949-1997
	Laona 6 SW* (estimated from minimum temp)	1948-1996
Cloud Cover	Minocqua Dam *	1978-1995
Solar Radiation	Minocqua Dam * (estimated from cloud cover)	1978-1995
	Eau Claire Airport	1951-1997
Wind Speed	Eau Claire Airport	1949-1997
	Green Bay Airport	1949-1997
Snow Depth	Sugar Camp *	1948-1997
	Long Lake	1948-1995
	Minocqua Dam	1948-1997

* - Primary station for modeling

Land Cover

Land cover affects the hydrologic response of a watershed by influencing infiltration, surface runoff, and water losses from evaporation or transpiration by vegetation. The movement of water through the system, and subsequent erosion and chemical transport, all are significantly affected by the vegetation (*i.e.*, forest, grasses, and crops). The HSPF model segments for the study area consist of approximately 64.5% forest; 5.1% recharge wetland; 10.9% discharge wetland, 10.2% open water; 6.9% agricultural/pasture; 1.1% urban, 1% barren, and 0.4% shrubland (Table 5). The recharge and discharge wetlands, though not the predominant land cover, play an important role in the behavior of the water before it runs into the stream. The forested land cover associated with the rural areas, due to its predominance, is a significant influence on runoff as well.

Five categories of pervious land cover were defined for this study using WISCLAND (Wisconsin Initiative for Statewide Cooperation of Landscape Analysis and Data) and ancillary data layers. They are forest, agriculture/ pasture, urban pervious, discharge wetlands, and recharge wetlands. Variations in the rainfall-runoff process resulting from variations of soil type and slope within these land-cover categories were not considered to be substantial in the Swamp and Pickerel Creek watersheds.

Table 5. Area in acres of WISCLAND land cover category for Hydrological Simulation Program-Fortran (HSPF) segments

Segment	Urban acres	Ag/pas acres	Forest acres	Water acres	Rechrg acres	Dischrg acres	Barren acres	Shrub acres	Total acres
10	0	281.7	1561.5	16	221.4	0	44	0	2,124.6
20	495.3	686.5	2,424.7	2,019.6	219.6	114.5	158.2	0	6,118.4
30	0	131.1	2,090.9	12.9	4.8	264.5	2.2	7.9	2,514.2
40	0	155.6	1,246.6	0.9	70.8	290.6	57.8	6.7	1,828.9
50	0	16.8	174.7	1.4	0	52.3	13.2	12.4	270.9
60	0	157.2	413.5	209.7	0	418.4	55	4.8	1,258.5
70	0	96	356.6	71.2	3.8	170.9	21.8	9.1	729.4
80	0	143.4	680.5	0.4	89.4	110.8	48.7	3.8	1,076.9
91	0	189.4	337	0	2.7	102.2	36.6	0.3	668.2
92	0	0	90.5	0	0	93	0	0	183.5
101	0	230.7	811.9	3.8	130.1	193.5	9.2	11.5	1,390.7
102	0	0	260.7	1.5	1.4	89.8	0	0	353.3
110	0	4.4	329.7	48.4	40.9	0	0	2.3	425.6
121	0	0	115.5	0	0	45.2	0	2.6	163.3
122	0	0	258.9	0	21	31.6	0	0	311.5
130	0	178.3	472.3	1.1	69.5	110.9	9.8	7.4	849.4
140	0	0.1	191.9	0	4.2	84.7	0	0.1	281
150	0	167.5	295	1	241.2	153	0.8	17.5	875.9
160	0	41	1,147.5	19.4	0	362.3	0	2.2	1,572.4
170	0	72.3	499.2	2.2	17.2	156.6	5.3	10.8	763.6
180	0	76.6	1,571	17.2	79.4	412	0	33.8	2,189.9
190	0	7.2	771.5	2.2	53	219.9	0	1.4	1,055.2
200	0	67	890.1	81.3	22.5	50.6	0	0	1,111.5
210	0	181.1	3,451.4	1,031.6	138.9	0	6.9	0	4,809.9
220	0	67.8	1,269.1	0	41.6	0	2.9	0	1,381.3
230	0	73.4	1,581.5	26.5	187.5	0	0	0	1,869
250	0	20.1	981.2	0	18.1	631.1	0	0	1,650.5
260	0	28.4	2,001.1	714.9	67.6	640.8	3.3	9.9	3,466.1
270	0	9.4	990.5	0	120.4	217.4	0	1.8	1,339.4
280	0	0	88.7	0.7	42	0	0	0.2	131.6
290	0	17.7	637.3	226.8	135.7	0	0	2.6	1,020.2
300	0	1.9	200.2	0	49.5	0	0	1.6	253.2
310	0	0	287.6	26.8	74	0	0	3	391.5
320	0	0	805.7	93.6	139.1	0	0	1.3	1,039.7
330	0	0.4	110.8	6.8	12.3	0	0	1.5	131.8
SUM	495.3	3,102.9	29,396.4	4,638	2,319.6	5,016.3	475.7	156.3	45,595
%Basin	1.1%	6.8%	64.5%	10.2%	5.1%	11.0%	1.0%	0.3%	100.0%

Land cover area for each HSPF segment for the study area (Figure 3) was compiled from the WISCLAND satellite-derived land cover data for Wisconsin and ancillary data layers (Lillesand et al., 1998). Twenty-six WISCLAND Level II land cover categories for the HSPF segments were aggregated into eight Level I categories that included urban, agriculture, grassland, forest, open water, wetland, barren, and shrubland. Boundaries for wetland land cover were updated with the NMC wetland boundaries (from NMC, figure 2.30 in 4.2-3, p. 84. July 1996) updated with information from summer 1999 field visits (personal communication with Dave Siebert, WDNR, 3/22/2000). The town of Crandon accounts for the urban land cover in the model, all of which drains to Lake Metonga and is contained in one HSPF model segment. Inclusion of a separate urban category is warranted for this segment to represent pervious and impervious areas. In the “mine operation” scenario, this impervious category is used to represent portions of the plant site and other constructed facilities.

Wetlands

Since wetlands significantly impact the overall hydrology and ecology of the study area they warrant additional categorization based on hydrologic relations. Common names for wetlands include bogs, fens, marshes, swamps, etc. The Wisconsin Wetland Inventory Classification Guide (WDNR, 1992) defines a wetland as "an area where water is at, near, or above the land surface long enough to be capable of supporting aquatic or hydrophytic vegetation and which has soils indicative of wet conditions" [s.23.32(1), Wis. Stats.]. That is:

Wet soils + water near the surface + potential for wetland plants = wetland

Wetland land cover boundaries were derived from the WISCLAND land cover data updated with the NMC wetland boundaries. WISCLAND wetland boundaries are derived from the Wisconsin Wetland Inventory (WWI) digital linework (WDNR, 1998) whereas NMC wetland boundaries are based on wetland mapping completed in the 1980's and field visits by NMC and WDNR (personal communication with Dave Siebert, WDNR, 3/22/2000). Wetlands were subdivided into recharge or discharge wetlands based on: 1) the NMC wetland map for areas within the NMC study area (the definition of recharge and discharge wetlands used by the NMC is shown visually in the NMC Schematic of Wetland Types, Figure 2.30 in Appendix 4.2-3 of the EIR, July 1996, p. 84, with updates from summer 1999 field visits) and, 2) depth to water table and proximity to groundwater discharge points such as Swamp, Hemlock, and Pickerel Creeks for portions of the HSPF model segments that fall outside the NMC study area. In the latter case, the 1984 water table elevation map did not cover the HSPF model extent and although Forest and Langlade County water table elevation maps are available, their resolution (30 and 50 feet, respectively) is not sufficient to be useful. A water table elevation map, with 5 foot contours, was generated by use of the Analytic Element Model (Memo from Randy Hunt to Chris Carlson, March 2, 1999, "Modifications to the Crandon analytic element model and uncertainty analysis of mine inflow and impacts") to determine the depth to water table, and resulting wetland classification for wetlands that fall outside of NMC's project area.

For the HSPF model, the recharge and discharge wetlands categories were then placed in a pervious land (PERLND) classification in the User Control Input (UCI) portion of the model. After calibration, all of the hydrologic parameter values for both recharge and discharge wetlands were identical. Identical parameter sets were applied for recharge and discharge wetlands because available data were not sufficient to determine differences in hydrologic processes between those wetlands during calibration. The designations are maintained in the UCI file for future modifications of the model as more data become available.

Soils

Soil texture acreages for HSPF land cover segments were calculated by overlaying the Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) data for Forest County (Figure 9) with HSPF land cover (Appendix 1). Common soil types in Forest County and their properties are listed in Appendix 2, condensed from Section II-A of the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS) Technical Guide (1994). Langlade County soil types and their properties were determined from aerial photos and incorporated into the model, but not overlain with SSURGO data because that county has not been completed by the NRCS. In order to simulate water table movement in wetlands with HSPF Version 12, moisture capacity values were obtained from the Technical Guide to estimate the cohesion-water pore space, and effective soil porosity values were obtained from Rawls et al. (1983). Use of these soil properties in HSPF gives a strong physical basis to the simulation of water table movement. These data were used to calculate porosity to quantify the cohesion and gravitational water in the simulation of wetland water levels with the HSPF model. The resulting soil texture was aggregated into the following categories: loam, loamy sand and sandy loam, muck and peat, silt loam, variable (aggregated variable texture and unweathered bedrock), and aggregated/miscellaneous water.

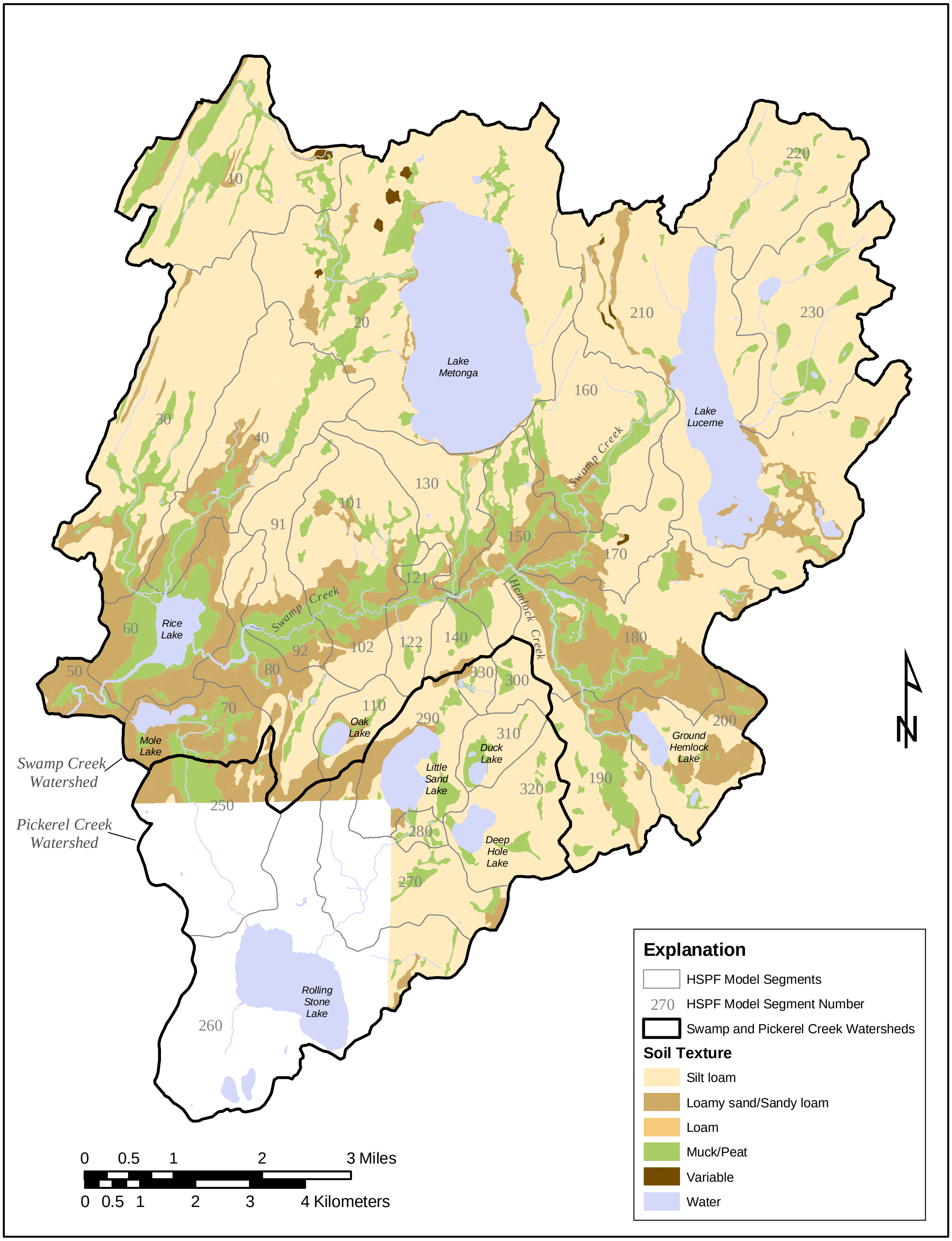


Figure 9. Soil textures for Forest County, Wisconsin (source: USDA NRCS SSURGO Data).

The model can use three types of porosity: (a) porosity in macropores, (b) porosity in the macropores in the upper soil layer, which is equal to (a) in this study and referred to as pore gravitational water (PGW), and (c) porosity in micropores, or pore cohesion water (PCW). The following series of calculations was performed *for each segment* for use in the model:

1. total number of acres in a land cover segment was determined
2. the soil texture percentage within the land cover segment was determined
3. the resultant percentage (2) was multiplied by an effective porosity (θ_e) constant for that soil texture
4. the resultant percentage (2) also was multiplied by an available water capacity (PCW) constant for that soil type
5. all the effective porosities from (3) were summed per segment
6. all the PCW values from (4) were summed per segment, and used as PCW in the model
7. then PGW was calculated by the difference of (5) minus (6):

$$PGW = \theta_e - PCW$$

DEVELOPMENT OF WATERSHED MODELS FOR SWAMP AND PICKEREL CREEKS

HSPF is a continuous-simulation model developed from the Stanford Watershed Model. Because it is a continuous-simulation model, it accounts for water stored in the watershed over time, which enables more realistic simulation of antecedent moisture conditions and flood sequences than can be done with event-based models, in which antecedent conditions are estimated. Annual and monthly water balances must be accurately simulated for this premise to be correct. Previous versions of HSPF have been successfully applied to simulate rainfall-runoff, sediment-transport, and pollutant-movement processes in watersheds for a wide variety of water-resources and environmental planning and management activities (Donigian et al., 1995). Version 12 of HSPF (Bicknell et al., 2001) was selected to simulate the rainfall-runoff process in the Swamp and Pickerel Creek watersheds because wetland water levels may also be simulated with this version of HSPF.

HSPF is a numerical model that approximates the terrestrial part of the hydrologic cycle by a series of interconnected water storage zones: an upper zone, a lower zone, and a groundwater zone. The amounts of water in these zones and the flux of water between the zones and to the stream or atmosphere are simulated on a continuous basis for a subarea of a given land cover and precipitation input. The fluxes of water between storage zones, and to the stream or atmosphere, are affected by a large number of model parameters. All the model parameters conceptually have meaning related to their physical attributes or processes in nature, but not all are physically measurable and those must be determined by calibration. The model parameters include threshold values, partition coefficients, and linear-reservoir release coefficients. The flow paths through the upper, lower, and ground water zones and the relations among the storage in the zones, streamflow, and evapotranspiration are shown in the flow chart in Figure 10. The upper zone usually consists of surface vegetation, ground litter, and the upper several inches of soil. Surface runoff and prompt subsurface flow (interflow) are affected by storage in the upper zone. The lower zone is the zone from which deeply rooted vegetation draws water. This water is then lost to the atmosphere through evapotranspiration. The lower zone does not directly discharge to the stream, but strongly affects the amount of water placed in interflow storage, which discharges to the stream. The ground water zone stores the water that supports base flow during periods of no rainfall. Water also can be lost to deep ground water that does not flow to the stream in the simulated area from the groundwater zone.

The simulated changes in wetland levels as a result of construction and operation of the proposed mine will be utilized for mitigation, monitoring, and bioassessment of impacts. HSPF Version 12 is newly developed and has not been extensively used, but the model was chosen for its ability to simulate wetland conditions before and after the dewatering of the mine and subsequent potential lowering of the groundwater table at the location of the proposed underground mine.

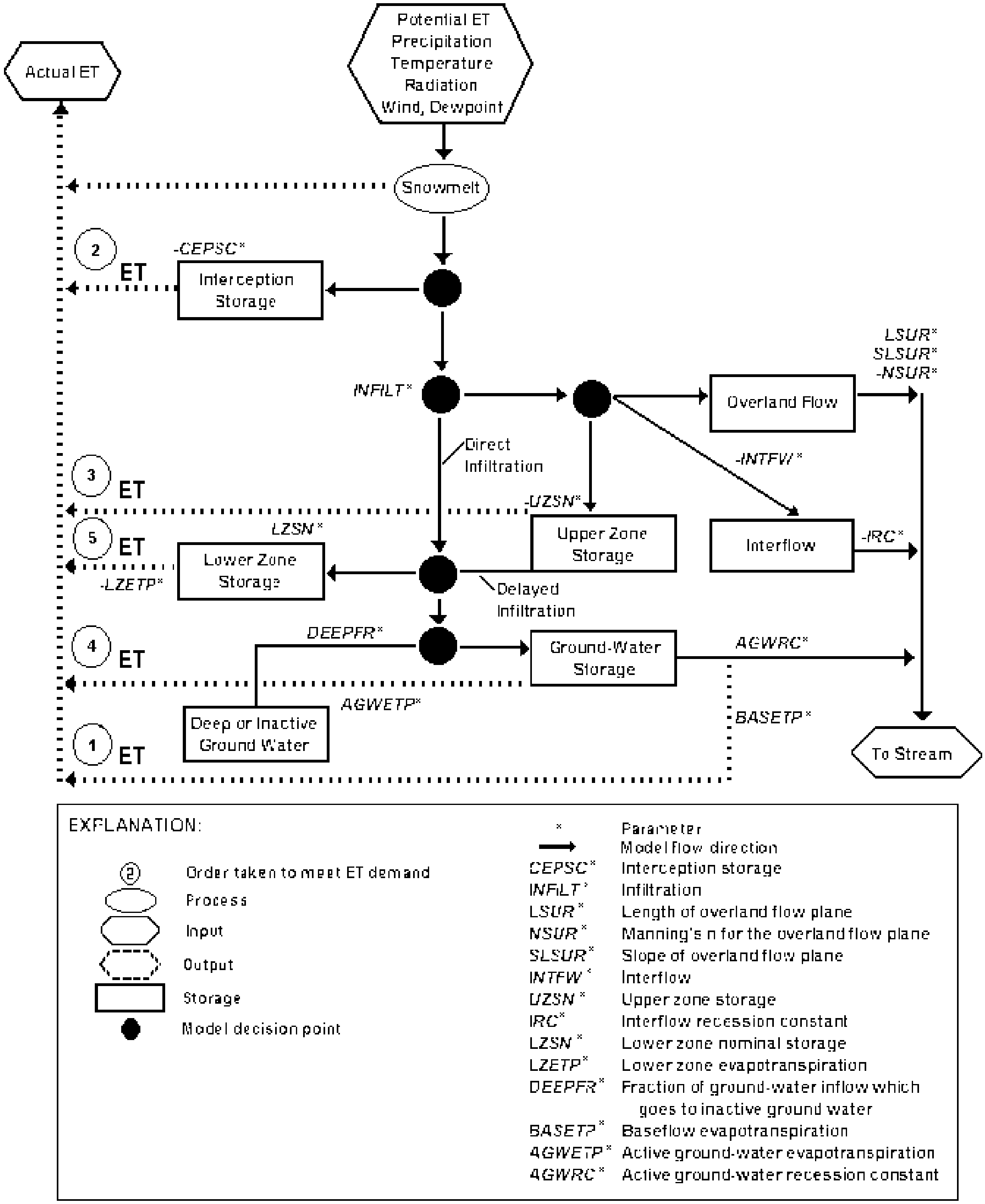


Figure 10. Schematic diagram of the Hydrological Simulation Program - FORTRAN model.

Version 12 of HSPF accounts for the different saturation conditions and routing of water that occurs in a seasonally saturated wetland. Simulation of the movement of the wetland water level (i.e., water-table elevation) is accomplished by equating lower-zone storage to the pore space in the soil above the minimum channel elevation less the pore space assigned to the upper-zone storage. The porosity in the lower zone is divided into pore space where water is bound to soil particles by capillary forces (cohesion-water pore space) and pore space where water drains downward because of gravitational forces (gravity-water pore space) as shown in Figure 11. The upper-zone storage is composed of the gravity-water pore space near the soil surface. As water enters the soil the water table may move up or down depending on the rate at which the pore space is filled by infiltration and drained to the stream as interflow and groundwater flow. Version 11of HSPF (Bicknell et al., 1997) limited the water in the saturated upper and lower zones to the original ambient ground-surface elevation as a maximum simulated water elevation. Version 12 removes this limitation and allows the water to be simulated above the land surface and literally “pond” as it would in nature where wetlands are found (see “Wetlands” section). The routing of surface runoff from the wetland may be simulated in three ways: 1) as a function of the land-surface slope (as applied in HSPF for surface runoff where water-table movement is not simulated), 2) using a power function, or 3) using a table where outflow is a function of the depth of ponding. The FTABLE approach was applied in this study because it was the only approach that allowed reasonable ponding to result in wetlands in the study area.

In the Swamp and Pickerel Creek watersheds, runoff from the majority of the overland flow areas passes through wetlands before entering the stream system. Thus, utilizing the topographic data available for the watersheds, runoff from the other pervious land covers (PERLNDs) was input to wetlands in each segment of the watershed as appropriate. For example, if 60 percent of the forest in a segment drained to wetlands before reaching the stream and 40 percent of the forest in a segment drained directly to the stream, the internal routing of runoff from PERLNDs would be set up to simulate this flow pattern. The fluctuating water table was only simulated for wetlands in the Swamp and Pickerel Creek watersheds. All other PERLNDs in these watersheds were simulated with the standard HSPF procedures.

Each watershed studied was subdivided into computational subwatersheds on the basis of physiographic features of the watershed (lakes, tributary streams, etc.), locations where output is desired, and land cover categories. The first two criteria were used to determine the segmentation of the watershed into subwatersheds as shown in Figure 5, based on interpretation of USGS 7.5 minute quadrangles. The subdivision on the basis of land-cover categories was applied to each of the subwatersheds as appropriate for the land cover in that subwatershed. Two broad categories of land cover are utilized in HSPF: pervious land cover (PERLND) and impervious land cover (IMPLND). A wide range of physical attributes can be assigned to a PERLND or IMPLND to represent various land-cover conditions. The pervious category was further subdivided into forest, agriculture/pasture, recharge wetland, and discharge wetland as previously described. In the study area, IMPLND is the urban category found in the town of Crandon, and was used for impervious areas at the plant site. Initial values for model parameters were selected on the basis of previous studies (Donigian and Davis, 1978), watershed characteristics, and preliminary model simulations.

Hydrological Relations

Simulation of runoff from a watershed provides insight into the processes that affect runoff. Though most parameters in HSPF cannot be physically measured, the parameter values should define the general relations among the processes that affect runoff. A conceptualized model of the physical setting for the study area and of the runoff process was developed prior to simulation to guide the calibration procedure. The conceptualization is important in guiding the calibration process because the number of parameters in HSPF permits similar results with different parameter sets. Thus, the model-parameter values and the User Control Input files (Appendix 3) developed in this study reflect the conceptualization of the watersheds and the hydrologic processes that affect runoff. Note that two significantly different conceptual models and two significantly different sets of parameters can both achieve good model-fit efficiency and correlation

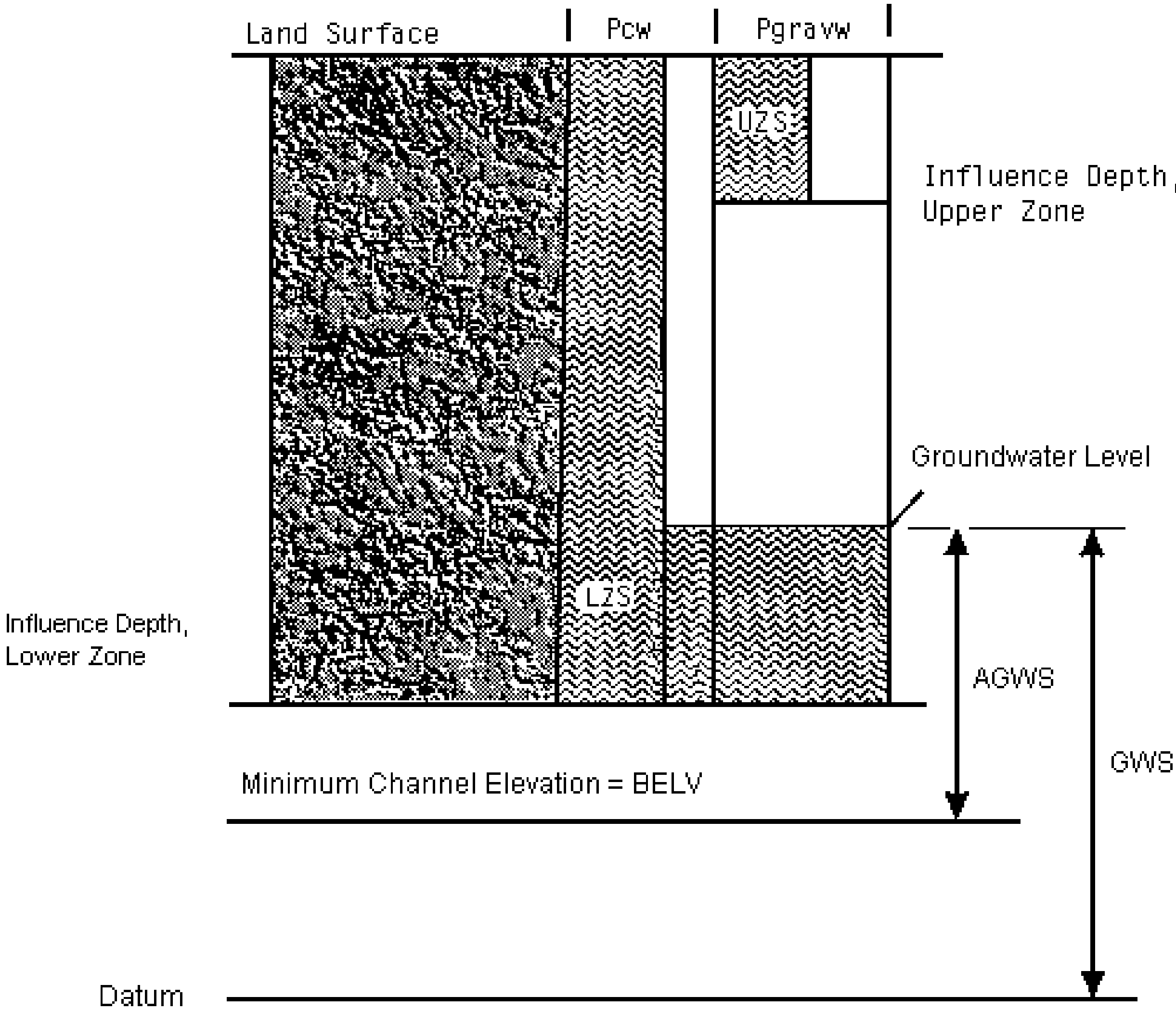


Figure 11.
Sketch of soil Moisture in the Unsaturated Zone
as simulated with Version 12 of HSPF

coefficients and other criteria when comparing simulated and observed data. Thus, a strong conceptual model is very important in modifying the parameters.

The conceptualized model for the two watersheds is based on an analysis of the physical setting in each watershed. The WISCLAND Land Cover database combined with the NMC wetlands layer allowed the model input to represent the physical setting in each watershed quantitatively. The eight Land Cover categories (urban, ag/pasture, forest, water, recharge wetland, discharge wetland, barren, and shrubland) were then recategorized for use in the model to five pervious land covers. They are forest, ag/pasture, urban pervious, discharge wetlands, and recharge wetlands. Variations in the rainfall-runoff process resulting from variations of soil type and slope within these land-cover categories were not considered to be substantial in the Swamp and Pickerel Creek watersheds. The recharge and discharge wetlands, though not the predominant land cover, play an important role in the behavior of the water before it runs into the stream.   Because it predominates, the forested land cover associated with the rural areas is a significant influence as well.

Agricultural and pasture land within the two watersheds was differentiated from other pervious land covers by seasonal variations in the interception storage capacity parameter (MON-INTERCEP) to reflect the different stages of vegetative growth of crops. Forested land was represented in a similar manner. Different seasonal variations in the foliage of deciduous trees was simulated by monthly variation in interception storage capacity.

The conceptualized model for the two watersheds also recognized the importance of the high water table, ground water and surface water interaction, groundwater contribution to surface water, and the influence of discharge wetlands and the low gradient in the areas adjacent to the streams. As previously described, the parameter sets are the same for both types of wetland, and both receive water from adjacent areas. GIS-based data are the only differences between the two types of wetlands. The low-flow characteristics of the watershed were simulated using the model parameters that controlled the groundwater flow regime, such as the fraction of inflow to the groundwater that recharges deep aquifers (DEEPFR), and the active groundwater recession constant (AGWRC). The base flow evapotranspiration (BASETP) in the model was 0.00. Frozen ground and snowmelt runoff also greatly influence runoff in the spring.

The values for the DEEPFR parameter, which controls the amount of recharge to deep aquifers that do not affect streamflow in the basin being simulated, were selected based on discussions with groundwater modelers at a meeting in Rhinelander, Wisconsin, in December 1998. Based on field evidence, low conductivity of the bedrock, and the results of particle tracking studies, it has been demonstrated that only small amounts of water are taken out of the basin through the deep aquifer. Further, and more importantly, particle tracking has determined that the groundwater watershed boundary extended to the west of the surface watershed boundary (Figure 12). This was confirmed by comparing the amount of water flow through the gage below Rice Lake (measuring the flow of a 32,740-acre watershed) with that through the gage above Rice Lake (26,374-acre watershed); the amount of flow was significantly larger below Rice Lake than the additional surface drainage area alone could account for. The model was adjusted by adding additional groundwater acreage believed to be influencing flow at the gage below Rice Lake (increased from 32,740 to 39,296 acres). The significantly improved agreement between simulated and observed flow below Rice Lake after adding the additional 6,556 acres supports this change. In the HSPF simulation, when the drainage area for the gage below Rice Lake was expanded, only the groundwater flow from this additional land in the ground watershed was directed to Swamp Creek; the surface runoff and interflow from this land was not. Only the area contributing groundwater flow was increased, not the area contributing surface runoff. The particle-tracking simulation also indicated that groundwater flow from the area east of Lake Lucerne does not contribute to the Swamp Creek gages above and below Rice Lake. However, this result appears to be related to assumptions regarding the water balance of Lake Lucerne rather than on physical

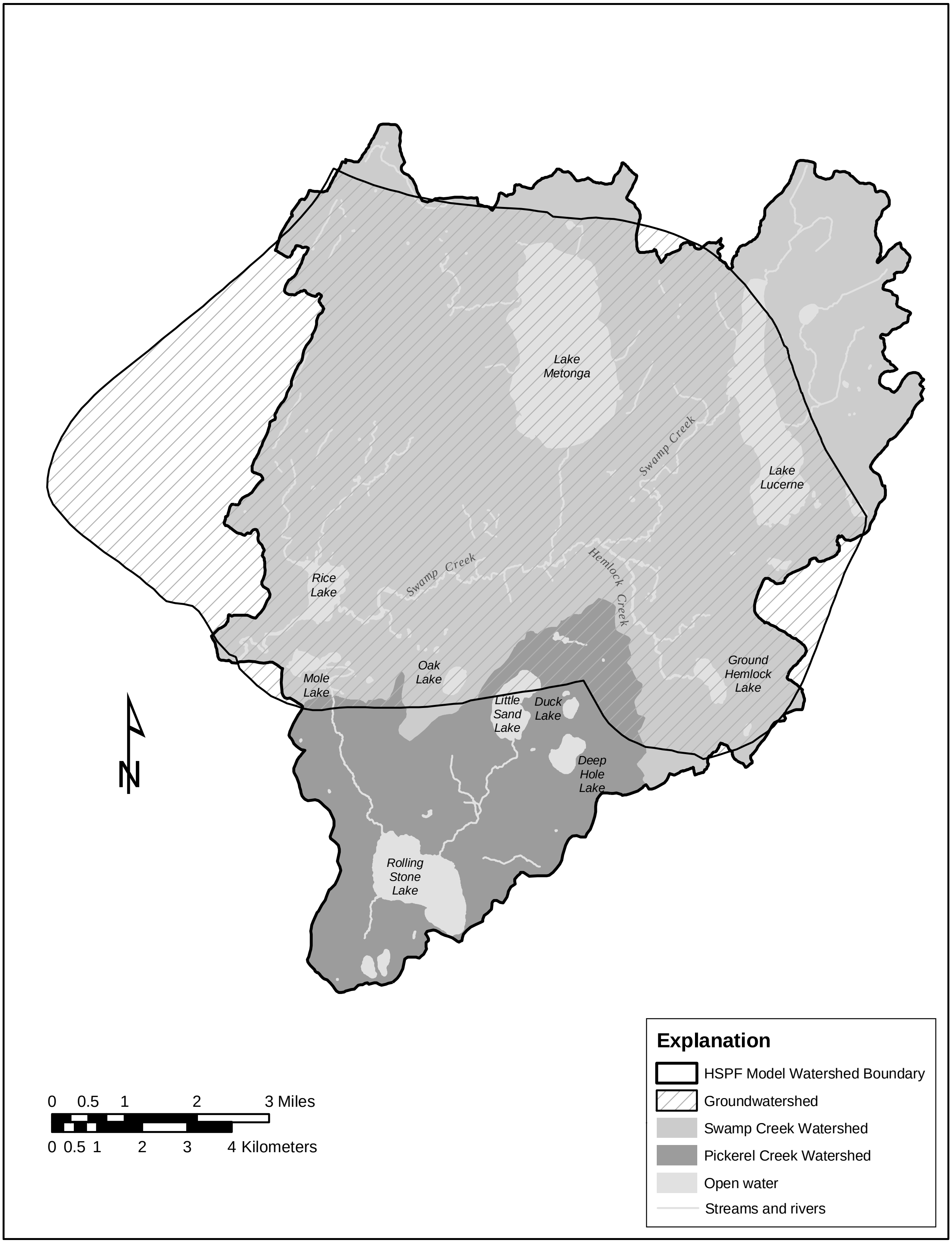


Figure 12. Groundwater contributing area for Swamp Creek below Rice Lake overlaid with HSPF model study area.

evidence. Therefore, the surface-watershed area east of Lake Lucerne was retained in the HSPF model of Swamp Creek. The ratio of simulated flow downstream of Lake Lucerne to the simulated flow at the gage above Rice Lake indicated 26 percent of the flow above Rice Lake came from Lake Lucerne, and the ratio of measured flow downstream of Lake Lucerne to measured flow above Rice Lake for three days in 1994 indicated that 14 percent of the flow for 3 low-flow days above Rice Lake came from Lake Lucerne. The simulated value is high relative to the limited measurements, but not unreasonably high. Substantial flows can come from Lake Lucerne and omission of the area east of Lake Lucerne probably would result in an underestimate of flows coming from Lake Lucerne. Documentation of inquiries regarding the influence of Lake Lucerne on area groundwater and runoff is found in other studies in the area, as illustrated in the March 2, 1999 memo from Randy Hunt (USGS) to Chris Carlson (WDNR), where Mr. Hunt states: "Presently there is not enough field information to elucidate Lake Lucerne's interaction with the groundwater system or the location of the groundwater divide".

The infiltration parameter (INFILT) was initially set to a single value per land cover to simulate relatively uniform soil conditions throughout the study area. This parameter was adjusted for each land cover, then further refined by soil types and hydrographic comparison. PGW and PCW values were calculated individually for each segment to account for the different soil types and their physical impacts on water retention in the upper zone storage. As previously stated in the "Soils" section, soil texture acreages for HSPF land cover segments were calculated by overlaying the NRCS SSURGO data for Forest County with HSPF land cover, and Langlade County by review of aerial photographs. These data were used to calculate porosity for the purpose of quantifying the cohesion and gravitational water in the simulation of wetland water levels with the HSPF model.

The simulation model for the watersheds incorporated a method to account for seasonal variation in runoff resulting from water table fluctuations. Seasonal fluctuation of the water table (high water table in the winter/spring and low water table in the summer) is a common occurrence in northern Wisconsin. Simulation of water-table fluctuations are most affected by two factors, the upper zone nominal storage (parameter UZSN) and lower zone evapotranspiration (parameter LZETP). For both of these parameters, seasonal variations are simulated using values which vary monthly. A high value of UZSN value in winter accounts for water frozen and stored in upper zones, a small value in summer accounts for cessation of spring melt and increased evapotranspiration. A larger LZETP value in the summer accounts for higher temperatures and more vegetative/root zone evapotranspiration (Table 6).

Table 6. Monthly variable model-parameter values for the best-fit calibration, of the Hydrological Simulation Program - FORTRAN to Swamp Creek near Crandon, Wisconsin for 60 months (January 1982 - December 1986) calibration.

Parameter	Watershed	J	F	M	A	M	J	J	A	S	O	N	D
UZSN Swamp Creek	forest	1.25	.95	.70	.55	.55	.35	.15	.20	.40	.50	1.35	1.35
	ag/ pasture	.80	.80	.85	.85	.90	.10	.10	.15	.30	.60	.90	.90
LZETP Swamp Creek	forest	.30	.30	.30	.40	.40	.40	.40	.40	.35	.30	.30	.30
	ag/ pasture, urban, re/disch wetland	.20	.25	.30	.30	.35	.35	.35	.35	.30	.30	.25	.15
MON-INTERCP Swamp Creek	forest	.02	.03	.06	.07	.09	.12	.12	.12	.09	.08	.06	.02
	ag/ pasture, urban, re/disch wetland	.01	.01	.02	.02	.02	.02	.08	.08	.06	.03	.01	.01

Calibration Procedure

The calibration of a surface water model is the primary means of developing the predictive quantitative relation of runoff to rainfall (Troutman, 1985). Complete calibration includes a verification phase in which the parameters optimized during the calibration phase are applied to a separate time period: this is necessary to confirm that the data in calibration years are not anomalous to the overall natural observed trends in a longer time period. The observed data set was divided into a calibration period and a verification period. The calibration period (January 1982 - December 1986) was selected on the basis of a continuous time series of data available in that period. The 60-month period of record available for calibration is sufficiently long to provide an adequate calibration (Donigian et al., 1984, p. 84; Linsley et al., 1982, p. 347). To obtain the most reliable calibration possible, the calibration period was selected to include as much lake level and wetland water level data as possible. The verification period consisted of four years (January 1978 - December 1981). Total, annual, seasonal, and monthly mass balances were determined to evaluate the quality of fit of the calibration.

Model calibration was achieved in a stepwise manner by first obtaining acceptable annual and monthly mass balances, and then adjusting parameters to obtain estimates of storm-runoff and runoff-duration curves of daily runoff. Calibration is facilitated by the hierarchical structure in HSPF in which the annual balance is most affected by one set of parameters, the monthly balances by another set, and storm runoff by a third set (Donigian et al., 1984). For example, the annual mass balance is primarily affected by varying lower zone evapotranspiration (LZETP), the fraction of percolation going to the deep aquifer (DEEPFR), the lower zone nominal storage (LZSN), and infiltration (INFILT) parameters, whereas seasonal mass balances are affected by varying upper zone nominal storage (UZSN), baseflow evapotranspiration (BASETP), variable groundwater recession (KVARY), and interception storage (CEPSC). Storm runoff is affected by varying INFILT, interflow (INTFW), and the interflow recession constant (IRC).

Many commonly used rainfall-runoff models have built-in calibration routines that estimate the best values of the model parameters as the parameter values that result in a minimization of an objective measure of the agreement between the simulated and observed runoff. The objective measures commonly used include the sum of the squared differences, the sum of absolute differences, and the weighted sum of squared differences (for example, more weight is given to matching high flows). An automatic calibration routine was developed for the Stanford Watershed Model (James, 1972), but due to the size of the model-output file and the complexity of the model, calibration could only be performed for 1 year of data at a time and the optimum parameter values for each year in the calibration would be averaged to determine the best overall parameter set. Averaging optimum parameters for several years is not a suitable approach when year-to-year variations in rainfall and runoff are large. Thus, no formal calibration routines have been developed or advocated for HSPF, and HSPF calibration must be accomplished by trial and error.

HSPF calibration is performed in a stepwise manner primarily using data available at stream flow gages and matching the overall water budget, the annual water budgets, the monthly and seasonal water budgets, and finally, considering storm-runoff volumes. In evaluating the monthly and seasonal water budgets and storm-runoff volumes, the relative proportions of high flows and low flows are considered. Several criteria must be utilized to determine if the quality of the fit between the simulated and observed runoff is acceptable. James and Burges (1982) recommend that graphical and statistical means be used to assess the quality of fit because trends and biases can be easily detected on graphs, and statistical measures provide an objective measure of whether one simulation is an improvement over another.

For the study area, model-parameter values reflecting the current, natural conditions were determined by calibration and verification utilizing runoff data from stream gages at Swamp Creek above Rice Lake and Swamp Creek below Rice Lake, as discussed in the “Hydrologic Data” section . Flow from much of the area potentially affected by the proposed mine is measured at the Swamp Creek above Rice Lake stream gage and is representative of the remaining affected area in the Pickerel Creek watershed. The data from the gage below Rice Lake were used to ensure flows and water levels in Rice Lake itself are correctly represented in the model.

Spatial verification was evaluated by applying the HSPF model with parameters determined for the Swamp Creek watershed to the Pickerel Creek watershed, simulating monthly lake levels, and comparing the simulated values to the measured values. No streamflow gaging stations exist in the Pickerel Creek Basin. Very limited lake level and discharge data were obtained from the EIR, the Tribes, USEPA, COE, Great Lakes Indian Fish and Wildlife Commission (GLIFWC), and others.

Calibration Criteria

Because calibration matches the overall water balance, the annual water balances, the monthly water balances, and considers storm-runoff and duration, several criteria must be considered to determine if the quality of the fit between the simulated and observed runoff is acceptable (USEPA, 1998).

For the overall and annual water budgets only the percentage error is considered. Donigian et al. (1984, p. 114) state that for HSPF simulation the annual or monthly fit is “very good” when the error is less than 10 percent, “good” when the error is between 10 and 15 percent, and “fair” when the fit is between 15 and 25 percent. The target for acceptable calibration and verification for this study was simulation of the overall and annual water budgets within 10 percent of the measured values.

Plots of observed and simulated runoff were prepared for the monthly water budget and checked for periods of consistent oversimulation or undersimulation of runoff. The quality of fit for monthly values was examined using three statistics: (1) the correlation coefficient between simulated and observed flows, (2) the coefficient of model-fit efficiency (Nash and Sutcliffe, 1970) between simulated and observed flows, and (3) the number of months for which the percentage error is less than a specified percentage (10 and 25 percent were used in this study). The average relative percentage error in monthly flows over the calibration period was also considered. Relatively small overestimates in months with very low flows may make this statistic a poor indicator of the overall quality of the fit. However, this problem was not substantial for Swamp Creek, and thus the average relative percentage error was considered in the calibration of HSPF to Swamp Creek. The correlation coefficient, C, is calculated as

$$C = \frac{\Sigma\,(Qm_I - Qm) * \sum(Qs_I - Qs)}{[\Sigma\,(Qm_I - Qm)^2\ \Sigma(Qs_I - Qs)^2]^{½}} \quad (1)$$

where Qm_I is the measured runoff volume for month I, Qs_I is the simulated runoff volume for month I, Qm is the average measured monthly runoff volume, Qs is the average simulated monthly runoff volume, and I = 1,..., N, where N is the number of months in the calibration or verification period. The coefficient of model-fit efficiency, E, is calculated as

$$E = \frac{\Sigma(Qm_I - Qm)^2 - \Sigma(Qm_I - Qs_I)^2}{\Sigma(Qm_I - Qm)^2} \qquad (2)$$

From the definition above it is clear that the coefficient of model-fit efficiency represents the fraction of the variance in the measured monthly flows explained by the model.

James and Burges (1982) suggest that an excellent calibration is obtained if the coefficient of model-fit efficiency exceeds 0.97, and present an example of an HSPF application where both the correlation coefficient and the coefficient of model-fit efficiency for daily flows exceeds 0.98. For the Stanford Watershed Model (a predecessor of HSPF), Crawford and Linsley (1966) reported correlation coefficients for daily flows between 0.94 and 0.98 for seven watersheds ranging in size from 18 to 1,342 mi^2 and with 4 to 8 years of data. Other researchers studying monthly flows have determined best model fits with lower coefficient values. Ligon and Law (1973) applied the Stanford Watershed Model to a 561-acre experimental agricultural watershed in South Carolina and obtained a correlation coefficient and a coefficient of model-fit efficiency for monthly flows of 0.966 and 0.931, respectively, for a 60-month calibration period. Chiew et al. (1991) applied HSPF to a 56.4 mi^2 agricultural watershed in west Tennessee and obtained a correlation coefficient for monthly flows of 0.8 for a 54-month calibration period. Duncker et al. (1995) applied HSPF to five watersheds in Lake County, Ill., ranging in size between 6.3 and 59.9 mi^2. For a 43-month calibration period, the correlation coefficients for monthly flows ranged between 0.93 and 0.97 and the coefficient of model-fit efficiency for monthly flows ranged between 0.86 and 0.92 for best-fit calibrations, whereas for regional calibrations (in which three of the watersheds were calibrated jointly) and verification (on two watersheds) the correlation coefficient ranged between 0.93 and 0.95 and the coefficient of model-fit efficiency ranged between 0.86 and 0.91. Duncker and Melching (1998) applied HSPF to three watersheds in Du Page County, Ill., ranging in size from 11.1 to 18 mi^2. For a 45-month calibration period, the correlation coefficients for monthly flows ranged between 0.93 and 0.96 and the coefficient of model-fit efficiency for monthly flows ranged between 0.86 and 0.92 for best-fit calibrations, whereas for regional calibrations (joint calibration of all three watersheds) the correlation coefficient ranged between 0.92 and 0.94 and the coefficient of model-fit efficiency ranged between 0.83 and 0.86. Verification for a 39-month period was not so successful. Two of the watersheds had good correlation coefficients (0.88 and 0.93) and coefficients of model-fit efficiency (0.67 and 0.88), but the third watershed had a correlation coefficient of 0.78 and a coefficient of model-fit efficiency of 0.34. Jarrett et al. (1998) applied HSPF to two watersheds in Jefferson County, Ky., ranging in size from 17.2 to 18.9 mi^2. Calibration to one watershed for a 36-month period yielded a correlation coefficient for daily flows of 0.91 and a coefficient of model-fit efficiency for daily flows of 0.82, whereas verification on the other watershed for the same 36-month period yielded a correlation coefficient of 0.88 and a coefficient of model-fit efficiency of 0.77. Finally, Zarriello and Ries (2000) applied HSPF to two watersheds in the same basin in Massachusetts with drainage areas of 44.5 and 125 mi^2. They obtained coefficients of model-fit efficiency between 0.9 and 0.98 for monthly flows and between 0.79 and 0.88 for daily flows over a 5-year calibration period. Donigian (Aqua Terra Consultants, written communication, 1997) indicated that in areas where snowmelt is a major factor and meteorological data are sparse, it may be difficult to obtain the high correlation coefficients and coefficients of model-fit efficiency reported in the previously listed studies. The targets for acceptable calibration and verification of monthly flows were set at a correlation coefficient greater than 0.85 and the coefficient of model-fit efficiency greater than 0.8.

Some targets for calibration and verification were difficult to achieve because:
1) Rain Gages - All precipitation data were measured outside of the Swamp and Pickerel Creek basins. Watersheds for which excellent calibrations have been obtained typically included several rain gages within the watershed (e.g., Jarrett et al. 1998). Because of the small spatial extent of high-intensity convective storms, errors in the rainfall input to models and the runoff estimate from models can be very large, even for small watersheds with several rainfall-gaging stations. For example, Schilling and Fuchs (1986) demonstrated that the magnitude of error in urban-runoff calculations for small watersheds resulting from rainfall, spatial variability may be greater than 100 percent in peak-discharge and runoff-volume estimation. Therefore, matching observed and simulated storm-runoff calculations for all storms is difficult. At best, the specific storm-runoff volumes can be examined to eliminate bias (that is, tendencies to overestimate or underestimate) in the simulated runoff volumes.

2) Data Limitations - The lake and wetland water level data available for calibration and verification are limited temporally. Additionally, the available data on elevations and lake/wetland characterization (e.g., bathymetry

and stage-discharge relations) are less reliable than other data utilized in model development. There were many data gaps in streamflow that had to be interpolated, thus, adding to the potential error.

Given these limitations in simulating storm runoff, the calibration criteria for storm runoff used in the HSPF Expert System (HSPEXP) (Lumb et al., 1994) were applied in this study. These criteria are (1) the error in total flow volumes for selected storms must be less than 20 percent, and (2) the error in total flow volumes for the sum of selected summer storms must be less than 50 percent. The maximum number of storms which may be used for the program is 36, with 25 (3 in summer months) and 19 used for Swamp Creek calibration above and below Rice Lake, respectively. There is a different number of storms because the data below Rice Lake was available in only a 45-month continuous time series rather than 60 months. A total of 19 storms (7 in summer months) were used for Swamp Creek verification. These criteria were refined during calibration (as suggested by Lumb et al. (1994) to 15 percent for all storms and 20 percent for summer storms. In the Quality Assurance Project Plan (QAPP) (USEPA, 1998), it was proposed to compare storm runoff volume frequency for measured and simulated storms. However, because flood frequency was not an important factor to the impact assessment for the proposed mine, the frequency comparison was not done.

The QAPP proposed that calibration and verification of “lake-level” and “wetland-water level” data, as distinct from stream flow data, would be evaluated using correlation coefficients and coefficients of model-fit efficiency. This was not done because available lake and wetland water level data were not sufficient to calculate meaningful values of these statistics. Instead, the quality of calibration and verification of simulated lake levels was determined by the average absolute error between the simulated and observed lake levels. Further, the wetland water-level data represented a fixed point in a large wetland, whereas the water levels simulated with HSPF represented an average over the entire wetland area in a subwatershed. Therefore, the measured and simulated values can only be compared qualitatively. That is, the simulated water table was checked to see if it rose and fell in the appropriate times of the year, and the range in simulated water levels was similar to the range of measured water levels.

The simulation of daily flows was checked by comparing the observed and simulated runoff-duration curves and time series. General agreement between the observed and simulated runoff-duration curves indicates adequate simulation over the range of the simulated flow conditions. Substantial or consistent departures between the observed and simulated runoff-duration curves indicate inadequate calibration. Certain characteristics of the model contribute to differences between the simulated and observed runoff-duration curves. For example, the effects of impervious areas that are not hydraulically connected to the drainage system are not explicitly simulated in the model. These are impervious areas that generate runoff that does not directly enter the stream channel or other parts of the drainage system. Runoff from these areas drains across adjacent pervious areas and may infiltrate before reaching the drainage system.

Three statistics are utilized to evaluate the high-flow/low-flow distribution indicated in a flow-duration curve numerically. These statistics are:
1) The <u>error in the mean low-flow-recession rates</u> based on the computed ratios of daily mean flow today divided by the daily mean flow yesterday for each day for the highest 30 percent of the ratios less than 1 (i.e. during flow recession). The default allowable difference (Lumb et al. 1994) in the mean low-flow-recession rate is $\leq$ 0.03. This value was the target value for this study. The value of $\leq$ 0.02 in the QAPP was a typographical error.

2) The <u>error in the mean of the lowest 50 percent</u> of the daily mean flows. The default allowable error is $\leq$ 10 percent (Lumb et al., 1994).

3) The <u>error in the mean of the highest 10 percent</u> of the daily mean flows. The default allowable error is $\leq$ 15 percent (Lumb et al., 1994)

Channel routing of flows is an integral part of this study. HSPF Version 12, which simulates wetland saturation and routing through wetlands, is a new enhancement of HSPF. Simulated runoff is not delivered to the stream instantaneously, but is routed through the wetlands in areas where they have a large influence, especially the recharge wetlands along Swamp Creek. Other adjustments and modifications in the application of HSPF to Swamp Creek, the necessity for which became apparent during the model development, include: 1) routing adjustments to simulate ponding in the wetlands at several times during the year without dampening the hydrological response in the system; 2) the addition of acreage to the west of Rice Lake to account for the difference in areal extent of the groundwater watershed and surface water watershed (Figure 12), discussed previously in the “Hydrological Relations” section; 3) adjustment of the potential evapotranspiration (PET) coefficient to better reflect the actual evapotranspiration at the site; and 4) adjustment of infiltration through the upper and lower zone storage into the deep fraction (DEEPFR) to reflect the amount of water in the system in the upper layers and the minimal amount lost to the deep, inactive groundwater system. All of these points are tied into the conceptualized model of the study area, discussed in the “Hydrological Relations” section of this document.

Calibration Steps Applied in this Study

The steps and procedures used in running the HSPF model are: 1) utility software is used to build the Watershed Data Management (WDM) file, to add HSPF time-series input, and to build data sets to store HSPF time series output; 2) the User Control Input (UCI) file is compiled; and, 3) the expert system HSPEXP (Lumb et al., 1994) is used to assist in the calibration of HSPF. Model calibration also was facilitated by a software program (FITQUAL) which was developed for statistical analysis of monthly flows from this model. The following is a brief outline of the procedures; additional details can be found in Lumb et al. (1994).

<u>UCI File</u>

The HSPF UCI file contains all of the input to HSPF except the time series data. The UCI file contains the options, parameters, watershed characterization data, and information to control the interaction with the WDM file (*i.e*., the data sets for input and output time series data). The modeler changes the chosen parameter(s) in the UCI for each model run, runs the model, then analyzes the results to determine the next steps, based on whether the previous run resulted in better calibration results. The following is a brief outline of the contents of a UCI file for simulation of hydrology in a watershed:

GLOBAL block	Title and time span of the run
OPN Sequence block	List of model operations (land & stream segments) in order of simulation
PERLND block	Option flags and parameters defining pervious land segments
IMPLND block	Option flags and parameters defining impervious land segments
RCHRES block	Option flags and parameters defining river segments (reaches)
FTABLES block	Tables defining volume vs. discharge relation for the reaches
EXT SOURCES block	Specification of input (meteorologic) time series from WDM file
EXT TARGETS block	Specification of output time series to WDM file
SCHEMATIC block	Connectivity of the watershed segments and areas of land segments
MASS-LINK block	Specification of material (water) transfers between watershed segments

One of the most critical elements is the storing of the records from simulation into the WDM file which will then be combined with observed data to compute the statistical measures of calibration status in the HSPEXP program. The eight standard computed time series used with HSPF are:

1. simulated total runoff (inches),
2. simulated surface runoff (inches),
3. simulated interflow (inches),
4. simulated base flow (inches),
5. potential evapotranspiration (inches),
6. actual evapotranspiration (inches),
7. upper zone storage (inches),
8. lower zone storage(inches).

In addition, for this project, time series of lake and wetland water-surface elevations were computed and stored in the WDM for comparison with available observed data.

<u>WDM file</u>

The WDM file is a binary file that is used to store hydrologic, hydraulic, meteorologic, and water-quality data and is the repository for time series data associated with the model application. During simulations, HSPF obtains time series input data, such as rainfall from the WDM file; and writes output time series data, such as streamflow to the file. Subsequent to simulation, utility programs access the data for analysis and display. WDM files are created and maintained using several utility programs, including ANNIE (Flynn et al., 1995), IOWDM (Lumb et al., 1990), METCMP (unpublished), and SWSTAT(unpublished).

A WDM file contains multiple time series data sets. Each data set contains a specific type of data, such as streamflow at a specific site or air temperature at a weather station. Each data set contains attributes that describe the data, such as station identification, ID number, time step, latitude, and longitude.

The time series data for the WDM file for the study area were processed at the USGS District office in Madison, Wisconsin, with assistance from the USGS District office in Urbana, Illinois. This procedure included reformatting the data to WDM format, filling any missing periods with data from nearby stations (or other estimation methods), developing a composite rainfall record for the Swamp and Pickerel Creek watersheds, and creating hourly records of rainfall, solar radiation, and air temperature for input to the model.

The ANNIE program contains a set of procedures to organize, manipulate, and analyze data needed for hydrologic modeling and analysis. ANNIE enables the user to perform tasks related to data management, tabular and graphical presentation, and input preparation for hydrologic models interactively. These capabilities were utilized throughout the modeling process to aid the modelers via the creation of plots, for example, of flow and wetland ponding.

<u>HSPEXP</u>

The HSPEXP program was used to assist in calibrating HSPF for the Swamp Creek watershed. This expert system software was developed to assist less experienced modelers with calibration of a watershed model and to facilitate the interaction between the modeler and the modeling process. In this system, a set of conditions is developed for each of the major calibration phases: overall water balance, low/base flow, storms, and seasonal adjustments. To facilitate communication between the HSPEXP system and the user, seven error terms are computed by the system from simulated and observed streamflow time series:

1. error in total runoff volume for the calibration period,
2. error in the mean of the low-flow-recession rates based on the computed ratios of daily mean flow today divided by the daily mean flow yesterday for each day for the highest 30 percent (default) of the ratios less than 1.0,
3. error in the mean of the lowest 50 percent of the daily mean flows,
4. error in the mean of the highest 10 percent of the daily mean flows,

5. error in flow volumes for selected storms,
6. seasonal volume error, June-August runoff volume minus December-February runoff volume error, and
7. error in runoff volume for selected summer storms.

In addition, other statistics are computed and output by the program: the simulated surface runoff and interflow volumes, and the simulated actual evapotranspiration and the potential evapotranspiration. In this study, all these statistics were utilized except 6, the seasonal volume error, because for this watershed June - August and December - February both are low flow periods and this comparison of "seasons" really does not reveal basic shortcomings of the model.

Analysis of the influence of snow and snowmelt in the study area also was facilitated by the capabilities of the ANNIE program. An example is shown in Figure 13. The reduction in observed snow depth, which started at 26 to 36 inches, and then dropped to zero within a two week timeframe in April, coincided closely with a dramatic increase in observed discharge from 50 cfs to over 150 cfs in the same time interval. The measured precipitation at the same time was less than 0.1 inches on two or three days of the two week interval. As the watershed was further examined, this snowmelt pattern recurred consistently.

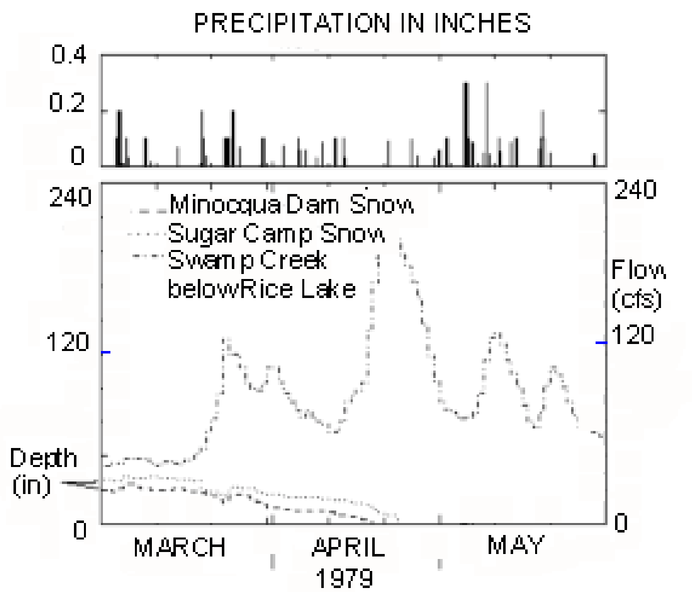


Figure 13. Typical relation between snowmelt and streamflow for the spring in the Swamp Creek watershed near Crandon, Wisconsin.

Storms were selected for inclusion in the HSPEXP computed statistics based on visual examination of observed hydrographs and storms with peak flows $\geq$ 60 cfs were used (Table 7). It should be noted that these values sometimes represented high snowmelt flows not necessarily related to high precipitation. Storms which were of a shorter runoff duration (2 - 3 days) were expanded for use in the model to a five day minimum runoff duration to better visualize the peak and recession of the storm plots.

As the model was run with each parameter adjustment, the statistical results for the error terms were reviewed to determine whether the parameter adjustment(s) had been successful in improving the agreement between observed and simulated results. Furthermore, after graphics and statistics were reviewed following a model run, the modeler could use the HSPEXP ADVISE option, which provides the user with advice on which model parameter(s) to change, the direction of change, and a brief explanation. The

ADVISE option was rarely utilized for this project, because the modelers rapidly gained an understanding of how to change parameter values to gain an improved simulation.

Table 7. Storms selected for calibration and verification of the Hydrological Simulation Program - Fortran model of Swamp Creek near Crandon, Wisconsin

Date verification period 19 storms	**Date calibration period 25 storms**
April 9-14, 1978	April 2-6, 1982
April 18-23, 1978	April 13-27, 1982
July 1-6, 1978 *	May 6-10, 1982
July 18-27, 1978 *	June 18-28, 1982 *
August 16-23, 1978 *	September 13-17, 1982
September 13-18, 1978	October 19-23,1982
March 19-30, 1979	November 11-15, 1982
April 14-May 1, 1979	March 3-10, 1983
May 19-24, 1979	April 12-16, 1983
June 16-21, 1979 *	May 7-11, 1983
July 10-19,1979 *	May 30-June 4, 1983
October 22-27, 1979	June 15-19, 1983 *
April 8-13, 1980	September 18-22, 1983
June 5-10, 1980 *	October 7-12, 1983
September 21-26, 1980	April 29-May 3, 1984
April 3-8, 1981	October 28-November 1, 1984
April 23-28, 1981	April 10-30, 1985
May 4-9, 1981	May 26-30, 1985
June 14-22, 1981*	July 5-9, 1985 *
	September 29-October 8, 1985
	October 31- November 4, 1985
	March 27-April 11, 1986
	April 14-18, 1986
	September 25-29, 1986
	October 11-16, 1986

*summer storms

A statistical evaluation further indicated the progress of the model calibration by computing the statistics of the model fit-efficiency, correlation coefficient, average absolute error, number of errors < 10%, and number of errors < 25% for the monthly flows. The difference between simulated and observed flow, divided by observed flow, is computed as a percentage error for each month; and the absolute difference in total monthly flow is computed as the total error in each month. These errors were used to determine whether simulated flows were too high in the summer or some other season or month, so that parameters could be adjusted accordingly. The model-fit efficiency also was used as a strong indicator of overall model calibration quality.

Verification Criteria

Verification through temporal transposition involves application of the runoff relations calibrated for a given time period to a second independent time period and utilizing discharge, lake-level, and well water level data to evaluate the reliability of the calibrated HSPF model. Verification of the calibrated parameter set consisted of simulating the verification period (January 1978 through December 1981) for each watershed with application of the calibrated parameter set. An acceptable verification was achieved if statistical results from the verification simulation were close to those statistical results for the best-fit model simulations for the calibration period, and graphical results from the verification simulation indicated no bias or trends in the simulated runoff. Verification utilized spatial transposition of the calibrated model as well as temporal transposition of the calibrated model. Verification through spatial transposition involves application of the model parameters calibrated for the Swamp Creek watershed to the Pickerel Creek watershed and utilizing lake-level and well water level data in the Pickerel Creek watershed (because no stream gage data are available) to evaluate the reliability of the calibrated HSPF model.

RESULTS OF MODEL CALIBRATION

Model-calibration results for the Swamp Creek watershed above and below Rice Lake are presented in two time frames: results of best-fit calibration above Rice Lake are presented based on continuous, available data for 60 months (January 1982 - December 1986), and the results of the calibration below Rice Lake are presented for a 45-month period of record (January 1982 - September 1985). The grand total and annual water balances for the observed data and the best-fit calibration during the study are summarized in Table 8, along with the comparison of observed to simulated results. Statistical results for monthly flows of the best-fit calibrations are summarized in Table 9. The average absolute relative error (*aare*) is calculated:

$$aare = \sum \frac{\text{absolute relative error}}{\text{number of months}} \times 100$$

where:

$$\text{absolute relative error} = \frac{\text{simulated - measured}}{\text{measured}}$$

Best-fit model calibration of the Swamp Creek watershed above and below Rice Lake produced “good” results relative to nearly all of the criteria proposed in the QAPP (USEPA, 1998). Best-fit model calibration statistics were similar to results reported from similar studies that applied the Stanford Watershed Model or HSPF (Ligon and Law, 1973; Dinicola, 1989; Chiew et al., 1991; Price and Dreher, 1991; Duncker et al., 1995; Duncker and Melching, 1998; Jarrett et al., 1998; Zarriello and Ries, 2000). For simulations with the best-fit model-parameter sets, correlation coefficients for monthly flows were 0.8828 and 0.8394 above and below Rice Lake, respectively, and coefficients of model-fit efficiency for monthly flows were 0.6067 and 0.4447 above and below Rice Lake, respectively (Table 9). The targets for acceptable calibration and verification of monthly flows are a correlation coefficient greater than 0.85 (which was achieved above Rice Lake and nearly achieved below Rice Lake) and a coefficient of model-fit efficiency greater than 0.80 (which was not met). The failure to achieve the model-fit efficiency criterion occurred because the variability of monthly flows in Swamp Creek is small relative to most streams modeled with HSPF (e.g., Duncker et al., 1995; Duncker and Melching, 1998; Jarrett et al., 1998) and so the basic monthly variability is small. With a small observed monthly variability, one or two poorly simulated months greatly distorts the fraction of monthly variability explained by the model. To illustrate this, for Swamp Creek above Rice Lake, if the errors for only 3 of the 60 months (April 1983, March 1984, and April 1986) are reduced to 0, the coefficient of model-fit efficiency rises from 0.6067 to 0.7506. Similarly, for Swamp Creek below Rice Lake, if errors for 3 of 45 months (March and April 1983, March 1984) are reduced to 0 and the coefficient of model-fit efficiency changes from 0.4447 to 0.6838. Note that these are months in which snowmelt contributes significantly to runoff. This demonstrates that a few poorly simulated months caused the model-fit efficiency not to meet the acceptance criterion. The initial goals of 0.8000 for model-fit efficiency and 0.8500 for correlation coefficient were acceptable for areas where snowmelt is a major factor and proximate meteorological data are sparse. The average absolute errors in the simulated monthly flows were 18.66 and 20.82 percent for Swamp Creek above and below Rice Lake, respectively.

Targets for error criteria for total volume, low flow recession, 50% lowest flows, 10% highest flows, storm volumes, and summer storm volume were met as shown in Table 10, except for low flow recession above Rice Lake. The statistical evaluation between the above and below Rice Lake locations indicates that the overall fit quality for each location is very similar.

Using the criteria of Donigian et al. (1984, p. 114), the best-fit simulations provided less than 10 percent error results for watershed total water balances and 10 -15 percent error annual water balances. The margin of error for total water balances was within 0.1 percent in Swamp Creek above Rice Lake, and 2.40 percent below Rice Lake (Table 10). Annual water balances were simulated with absolute errors from 1.4 to 14 percent in the Swamp Creek watershed above Rice Lake, calculated from Table 8. Many of the greater absolute percentage errors in the annual and monthly water balances reflect years and months with relatively low runoff. These periods yield absolute errors with large percentage differences but fairly small actual differences. The grand total water balance and annual water balances were most sensitive to changes in the upper zone nominal storage parameter (UZSN) and the parameter controlling recharge to deep aquifers, DEEPFR. However, based on hydrogeological information in the study area, only a very small portion of the deep groundwater does not discharge to Swamp Creek, thus, DEEPFR must be small.

Problems in the calibration process have also been encountered in other studies, but the difficulties appear to be unique in each watershed. Some of the situations encountered were:

1) The observed snow depth data indicated that snowmelt occurred a week or two weeks before the runoff hydrograph indicated a snowmelt-related rise. Thus, it was difficult to calibrate the snowmelt simulation properly and to match observed flows during the snowmelt period of March and April.
2) It was not always possible to meet the measured recession rate within the specified criterion of 0.03.
3) As discussed in the first paragraph of this section, the criterion for the model-fit efficiency could not be met.
4) Many attempts to get the results to show “ponding” (ground water elevations greater than the land surface elevation) by changing the surface runoff exponent (SREXP) were not effective, nor was changing the hourly recession constant (SRRC). Changes in wetland FTABLES proved to be effective.

The daily stream flow hydrographs simulated using the calibrated parameters are compared to the observed flows for the Swamp Creek watershed above and below Rice Lake in Figures 14 (A)-(C) and 15 (A)-(B). Simulated and observed monthly hydrographs are shown in Figures 16 (A)-(B). Close reproduction of the observed runoff-duration curves (Figures 17 (A)-(B)) indicates that the best-fit calibration parameter sets provide an acceptable simulation of rainfall-runoff relations on the Swamp Creek watershed in Forest County, Wisconsin. For flows exceeded 90% of the time, the match is close. The observed runoff-duration curves depart from simulated curves at flows below about 20-25 cfs.

Table 8. Observed and simulated values using the Hydrological Simulation Program - Fortran annual and grand total runoff in inches for the Swamp Creek watershed above and below Rice Lake, and comparison of simulated to observed data, at Mole Lake Reservation, Wisconsin.

Watershed	Values	1982	1983	1984	1985	1986	Grand Total	Average
Swamp Creek above Rice Lake (inches)	observed simulated	9.94 10.08	12.25 13.97	9.65 8.54	13.06 11.75	11.78 12.28	56.675 56.610	11.34 11.32
Ratio of sim/obs. Swamp Creek above Rice Lake	simulated/ observed	1.014	1.140	0.885	.900	1.042	-----	0.996
Swamp Creek below Rice Lake (inches)	observed simulated	9.12 9.7	11.36 13.1	9.33 8.5	8.28 (¾yr.) 7.4 (¾yr.)	na	38.09 38.70	10.3 (est. for 4 years)
Ratio of sim/obs. Swamp Creek below Rice Lake	simulated/ observed	1.064	1.153	0.911	0.894 (¾yr.)	na	-----	1.08 (est. for 4 years)

Table 9. Model-Calibration statistics for monthly flows for the Swamp Creek watershed above and below Rice Lake at Mole Lake Reservation, Wisconsin, simulated with application of the Hydrological Simulation Program - Fortran for a 60-month calibration period above and 45-month calibration period below (January 1982 - December 1986 and January 1982 - September 1985, respectively).

Watershed	Coefficient of Model Fit Efficiency	Correlation Coefficient	Average absolute relative error	Number of months when the difference between simulated and observed average monthly discharge was < 10%	Number of months when the difference between simulated and observed average monthly discharge was < 25%
Swamp Creek above Rice Lake	0.6067	0.8828	18.66	18 (of 60 months)	44 (of 60 months)
Swamp Creek below Rice Lake	0.4447	0.8394	20.82	12 (of 45 months)	31 (of 45 months)

Table 10. Statistics for the criteria used in the hydrologic simulation of the Swamp Creek watershed above and below Rice Lake at Mole Lake Reservation, Wisconsin, obtained with HSPF applied to a 60-month calibration period above and 45-month calibration period below (January 1982 - December 1986 and January 1982 - September 1985, respectively).

Swamp Creek Calibration	Total volume (in.)	Low flow recession rate	50% lowest flows (in.)	10% high flows (in.)	Storm volumes (in.)	Summer storm volumes (in.)
Above Rice Lake obs. & sim.	56.675 (obs) 56.610 (sim)	0.950 0.990	18.437 16.790	12.761 13.560	11.254 10.310	1.085 0.920
Below Rice Lake obs. & sim.	38.080 (obs) 39.000 (sim)	0.960 0.990	12.944 12.280	7.692 8.610	6.269 5.960	0.936 0.850
Error above Rice Lk. (%)	-0.100	-0.04	-8.900	6.3	-8.4	-15.2
Error below Rice Lk. (%)	2.400	-0.030	-5.100	11.900	-4.9	-9.
Error criteria (%)	±10.00	±0.03	±10.00	±15.00	±15.00 *	±20.00 *

* These criteria were tightened from the HSPEXP (Lumb et al., 1994) default criteria of ± 20.00% and ± 50.00%, respectively.

Figures 18 (A) - (D) show water-surface elevations for four wells located in wetlands in the Swamp Creek watershed. For the three year period 1984-1986, only 9 water-surface elevation measurements were made at each of these wells. As shown in Figures 18(A) and 18(C), respectively, the available data for Well WP-2U (Segment 80) and Well WP-6U (Segment 180) show only about 0.1 to 0.2 ft of variability in the water-surface elevation (with the exception of the outlier in May 1984 at Well WP-2U). Whereas for Well WP-4U (Segment 100) a variation of about 0.5 to 0.6 ft in water-surface elevation is shown in the available data in Figure 18b. It seems that these relatively small variations are an artifact of the very infrequent sampling rather than the true fluctuations in wetland water-surface elevations over a 3-year period. Data from Well WP-7U (Segment 190) indicates nearly 1.5 ft of water-surface-elevation fluctuations and has very good agreement with the simulated water-surface-elevation fluctuations (Figure 18(d). These last results give some confidence that HSPF is realistically simulating water-surface-elevation fluctuations in at least some wetlands in the Swamp Creek watershed.

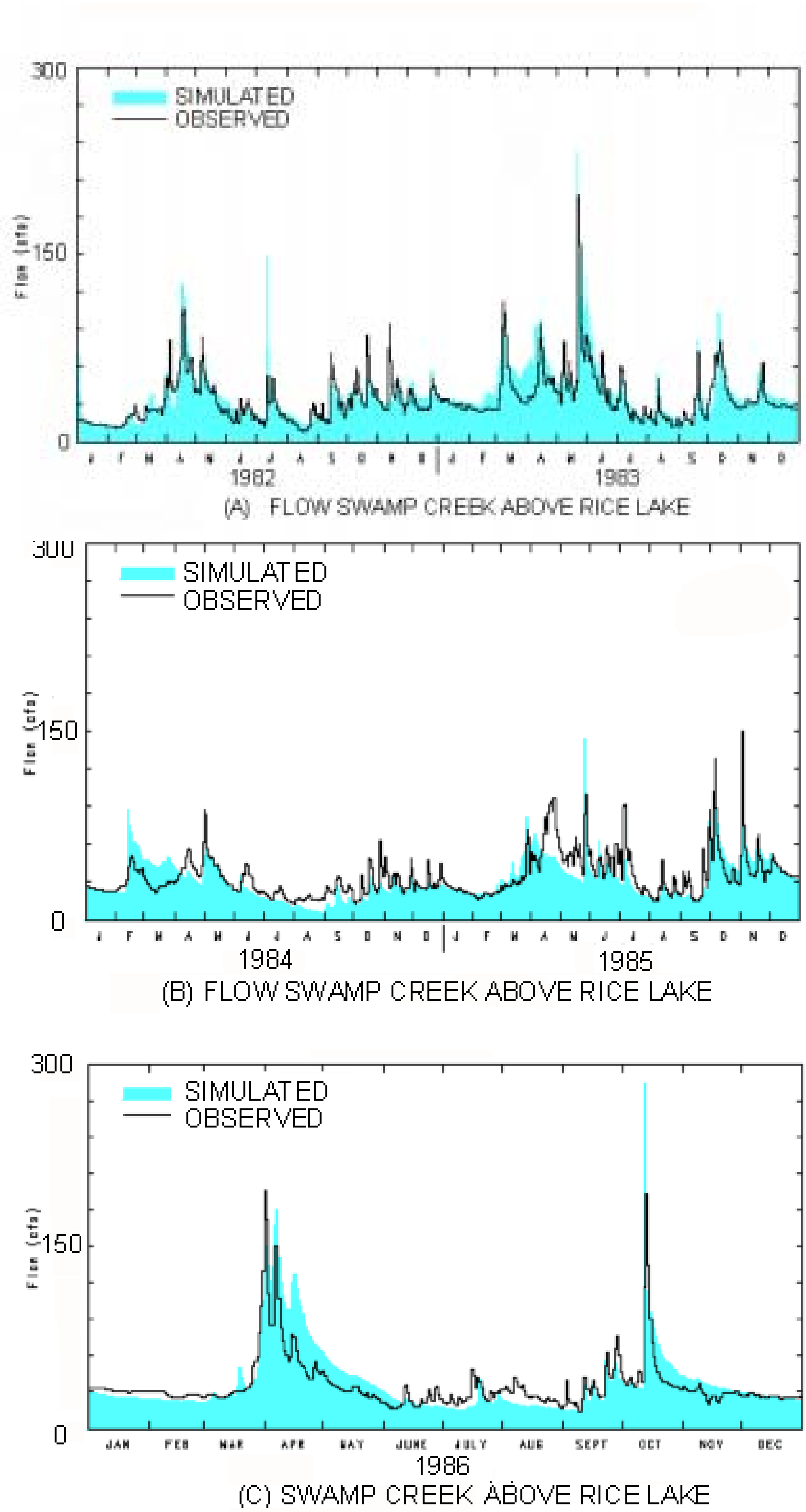
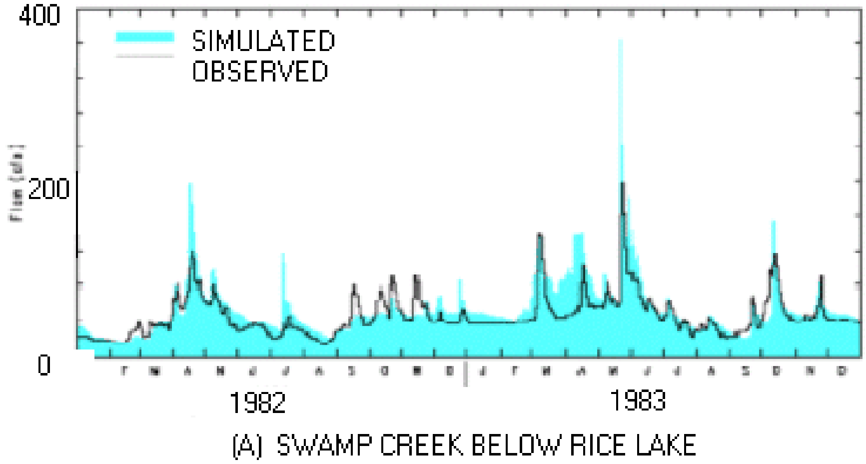


Figure 14. Daily flows observed and simulated with the Hydrological Simulation Program - Fortran for Swamp Creek above Rice Lake at Mole Lake Reservation, Wisconsin, for (A) 1982-1983, (B) 1984-1985, and (C) 1986.



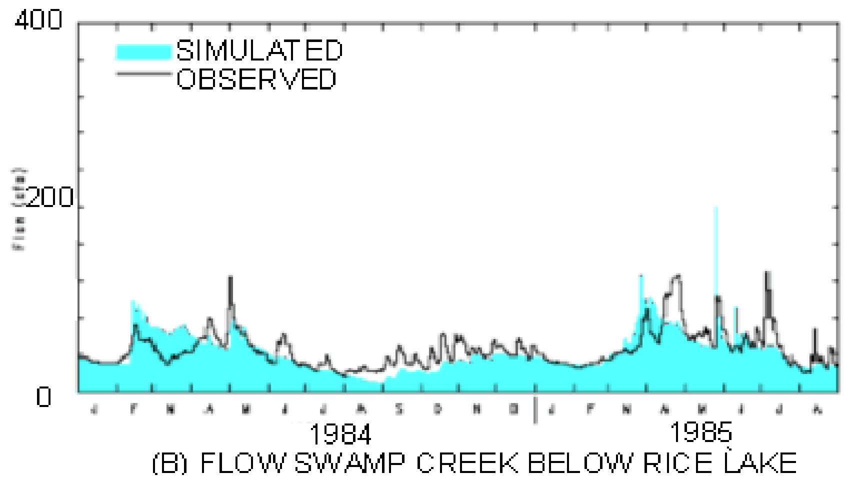


Figure 15. Daily flows observed and simulated with the Hydrological Simulation Program - Fortran for Swamp Creek below Rice Lake near Mole Lake Reservation, Wisconsin, for (A) 1982 - 1983 and (B) 1984 - 1985.

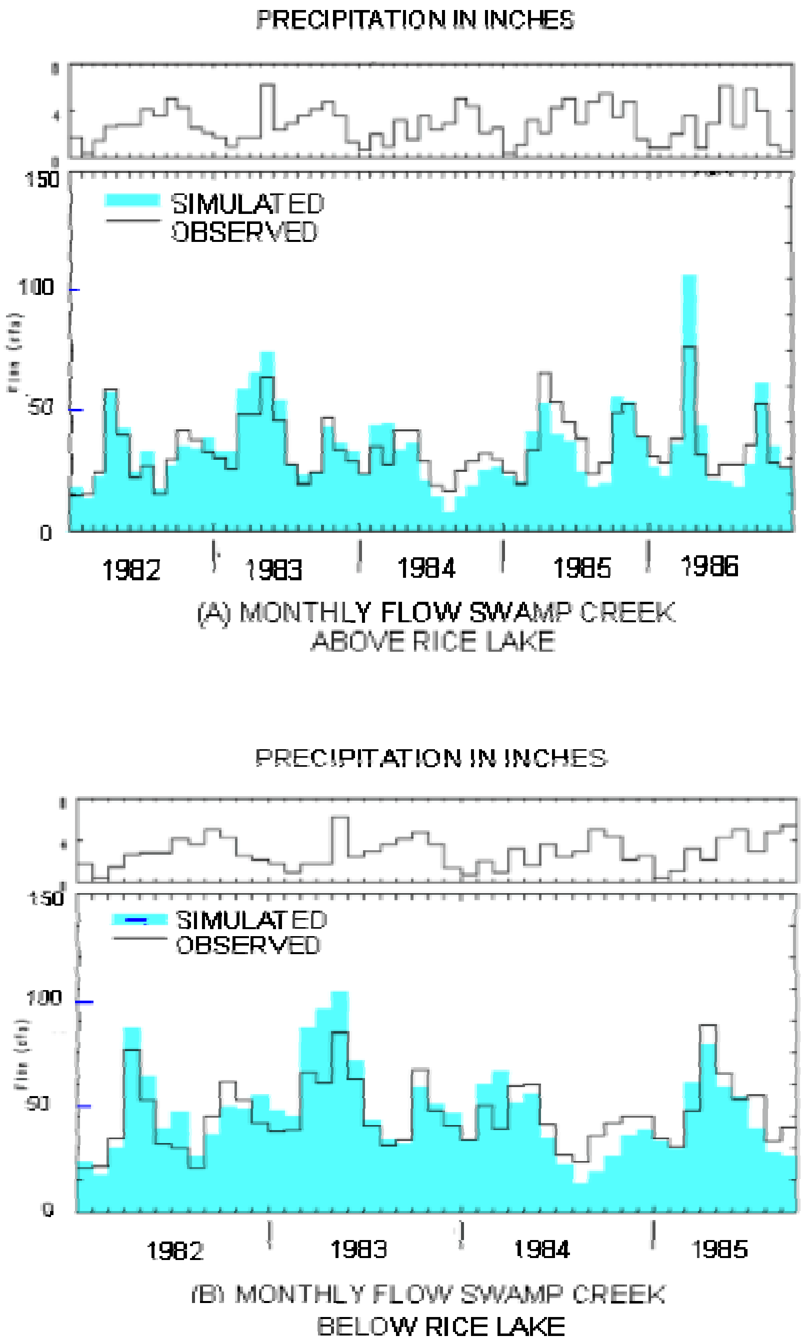
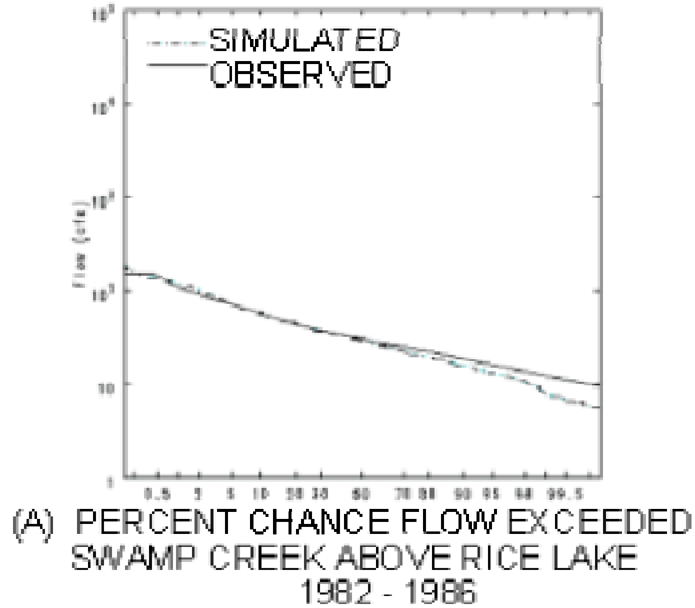


Figure 16. Monthly flows observed and simulated with the Hydrological Simulation Program - Fortran for (A) Swamp Creek above Rice Lake and (B) Swamp Creek below Rice Lake near Mole Lake Reservation, Wisconsin, for 1982 - 1986.



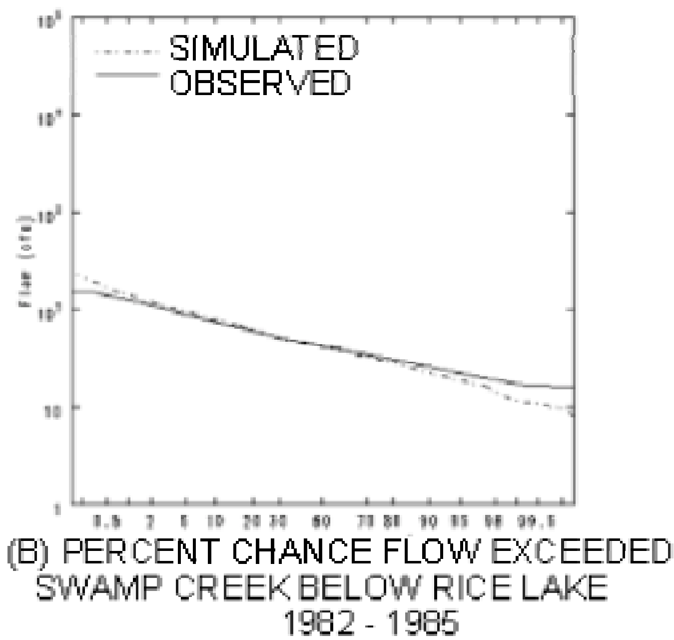
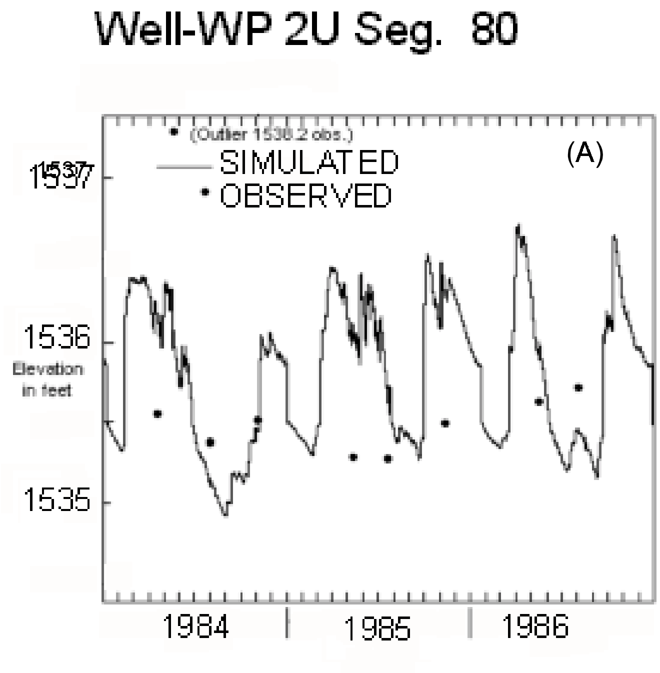


Figure 17. Daily flow duration curves observed and simulated with the Hydrological Simulation Program - Fortran for (A) Swamp Creek above Rice Lake and at (B) Swamp Creek below Rice Lake near Mole Lake Reservation, Wisconsin, for 1982 - 1986.



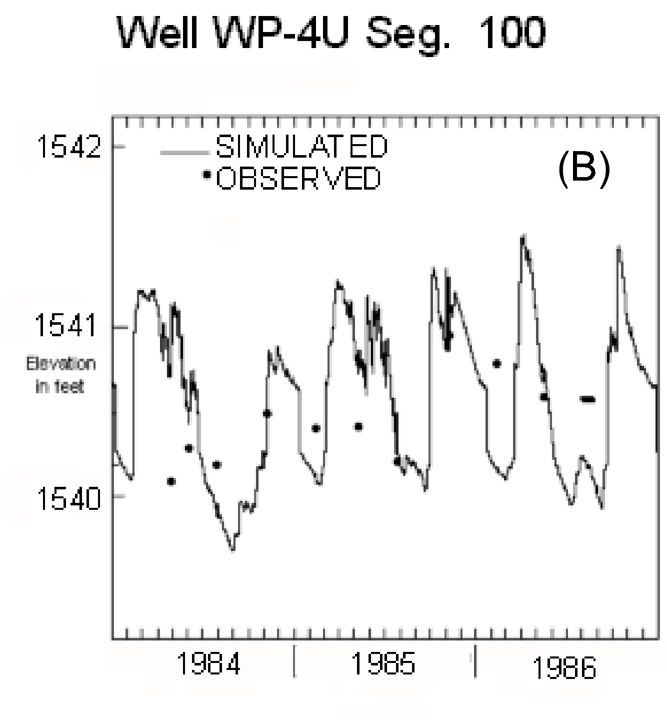
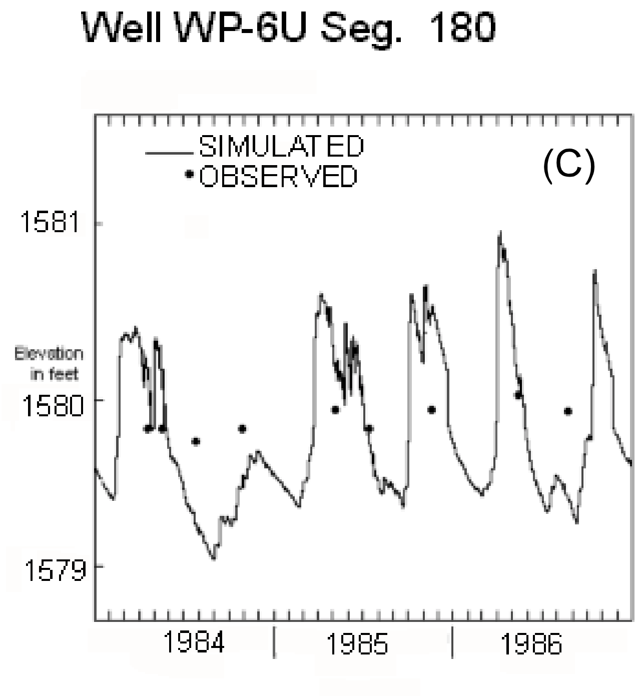


Figure 18. Wetland well water-surface elevations observed and simulated with the Hydrological Simulation Program - Fortran for (A) Well WP-2U in Segment 80, (B) Well WP-4U in Segment 100 (con't next page).



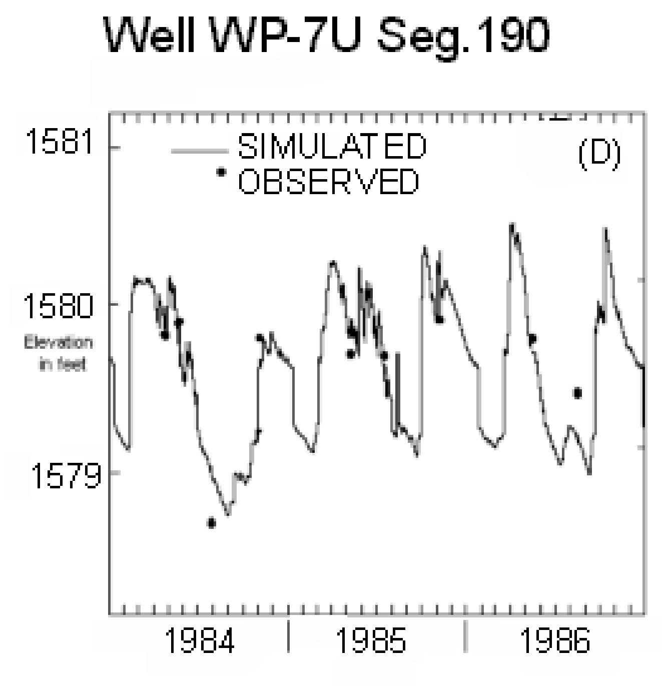


Figure 18 (con't). Wetland well water-surface elevations observed and simulated with the Hydrological Simulation Program - Fortran for (C) Well WP-6U in segment 180, and (D) Well W -7U in segment 190.

RESULTS OF MODEL VERIFICATION

Swamp Creek Temporal Verification

Model verification for the Swamp Creek watershed above and below Rice Lake produced “fair” results Relative to nearly all of the criteria proposed in the QAPP (USEPA, 1998). For simulations with the best-fit model-parameter sets from the calibration, correlation coefficients for monthly flows were 0.8229 and 0.8346 above and below Rice Lake, respectively, and coefficients of model fit efficiency for monthly flows were 0.4351 and 0.4826 above and below Rice Lake, respectively (Table 11). The targets for acceptable verification of monthly flows are correlation coefficients greater than 0.85 and coefficients of model-fit efficiency greater than 0.80. These targets were not achieved. As was found for the calibration period, this resulted because the variability of monthly flows in Swamp Creek is small relative to most streams and so the basic monthly variability is small. With a small observed monthly variability, one or two poorly simulated months greatly distorts the fraction of monthly variability explained by the model. As applied in the calibration of Swamp Creek above Rice Lake, if the errors for 3 of the 48 months in the verification period (April 1978, May and June 1979) are reduced to 0, the coefficient of model-fit efficiency increases from 0.4351 to 0.6793. For Swamp Creek below Rice Lake, 3 of 48 months (April 1978, March and May 1979) are reduced to 0 and the coefficient of model-fit efficiency changes from 0.4826 to 0.7039. Further, the correlation coefficient for both above and below Rice Lake improved to 0.8641 and 0.8936, respectively, with the omission of the outliers in the statistics. This demonstrates that a few poorly simulated months caused the model-fit efficiency and correlation coefficient not to meet the acceptance criteria, and that otherwise the monthly simulation is good. Average absolute errors in the simulations were 28.05 and 27.71 percent for Swamp Creek above and below Rice Lake, respectively.

Table 11. Model-verification statistics for monthly flows for the Swamp Creek watershed above and below Rice Lake at Mole Lake Reservation, Wisconsin, simulated with application of the Hydrological Simulation Program - Fortran for a 48-month verification period (January 1978 - December 1981).

Swamp Creek Watershed	**Coefficient of Model Fit Efficiency**	**Correlation Coefficient**	**Average absolute relative error (%)**	**Number of mos. when the difference between sim. and obs. average monthly discharge was < 10%**	**Number of mos. when the difference between sim. and obs. average monthly discharge was < 25%**
Above Rice Lake	0.4351	0.8229	28.05	13 (of 48 months)	23 (of 48 months)
Below Rice Lake	0.4826	0.8346	27.71	12 (of 48 months)	25 (of 48 months)

Targets for error criteria for total volume, low flow recession, 50% lowest flows, 10% highest flows, storm volumes, and summer storm volume were met as shown in Table 12, except for slight discrepancies from the criteria for 10% highest flow (15.3 percent error with a goal of 15.0 percent) above Rice Lake, and in the criteria for 50% lowest flow (-10.1 percent error with a goal of 10.0 percent) below Rice Lake. Parameter values could not be altered to get better results because as one criterion error value would improve another would worsen. The statistical evaluation between the above and below Rice Lake locations indicates that the overall fit quality for each location is very similar. The daily stream flow results for the calibrated model parameters is compared to observed flow for the Swamp Creek watershed above and below Rice Lake in Figures 19 and 20, respectively. Simulated and observed monthly discharges are shown in Figure 21.

Close reproduction of the observed runoff-duration curves for the verification (Figure 22) period indicates that the best-fit calibration parameter set, used for the verification period, provides an acceptable simulation of rainfall-runoff relations on the Swamp Creek watershed in Forest County, Wisconsin. The observed runoff-duration curve departs from both simulated curves at a flow of about 30 cfs. The verification plots differ from the calibration curves (Figure 17) in that there is a greater difference between the observed and simulated values for the low flow portions of the curve. A possible explanation for this difference is that low flows have greater statistical errors when comparing simulated and observed values because low flows are more common in the verification period. The average annual observed runoff of 10.21 inches per year in verification years is about one inch less (Table 13) than the average annual observed runoff in calibration years (of 11.3 inches per year).

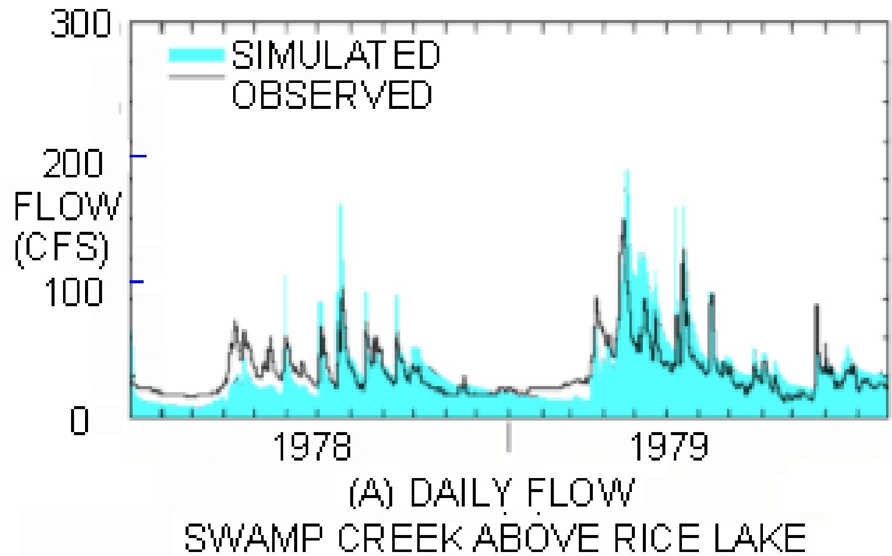
Table 12. Statistics for the criteria used in the hydrologic simulation of the Swamp Creek watershed above and below Rice Lake at Mole Lake Reservation, Wisconsin, obtained with the Hydrological Simulation Program - Fortran applied to a 48-month verification period (January 1978 - December 1981).

Swamp Creek Calibration	**Total volume (in.)**	**Low flow recession rate**	**50% lowest flows (in.)**	**10% high flows (in.)**	**Average of Storm peaks (cfs)**	**Summer storm peaks (in.)**
Above Rice Lake obs. & sim.	40.828 42.270	0.950 0.990	12.409 11.250	9.891 11.400	9.819 10.200	3.472 3.810
Below Rice Lake obs. & sim.	40.316 40.250	0.950 0.990	12.508 11.250	9.631 10.500	9.522 9.280	3.268 3.370
Error above Rice Lk. (%)	3.500	-0.04	-9.300	15.300	3.9	9.7
Error below Rice Lk. (%)	-0.200	-0.040	-10.100	9.000	-2.500	3.1
Error criteria (%)	±10.00	±0.030	±10.00	±15.00	±15.00	±20.00

Table 13. Observed and simulated using the Hydrological Simulation Program - Fortran annual and grand total runoff for the Swamp Creek watershed above and below Rice Lake at Mole Lake Reservation, Wisconsin.

Swamp Creek Watershed	**verification**	**1978**	**1979**	**1980**	**1981**	**Grand Total**	**Average**
Above Rice Lake (inches)	observed simulated	10.15 9.04	12.51 14.43	9.13 11.36	9.05 7.44	40.828 42.270	10.21 10.57
Above Rice Lake	simulated/ observed	0.891	1.153	1.244	0.822	-----	1.028
Below Rice Lake (inches)	observed simulated	10.07 8.6	12.80 13.3	8.76 11.0	8.69 7.3	40.316 40.250	10.08 10.06
Below Rice Lake	simulated/ observed	0.854	1.039	1.256	0.840	-----	0.997

Following the criteria of Donigian et al. (1984, p. 114), the best-fit simulations provided less than 10 percent error results for watershed total water balances and 10 - 15 percent error or 15 - 25 percent error annual water balances (Table 13) for the verification period. The margin of error for total water balances was within 3.50 percent in Swamp Creek above Rice Lake, and -0.20 percent below Rice Lake. Annual water balances were simulated with absolute errors from 10.9 to 24.4 percent in the Swamp Creek watershed above Rice Lake. Annual water balances were simulated with absolute errors from 3.9 to 25.6 percent in the Swamp Creek watershed below Rice Lake. As in calibration, many of the greater absolute percentage errors in the annual and monthly water balances in verification reflect years and months with relatively low amounts of runoff. These periods yield absolute errors with large percentage differences but fairly small actual differences.



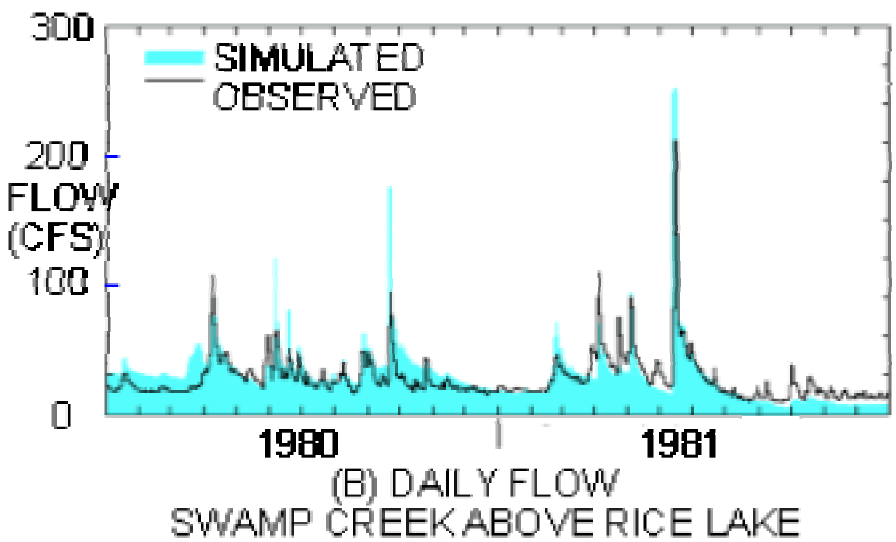
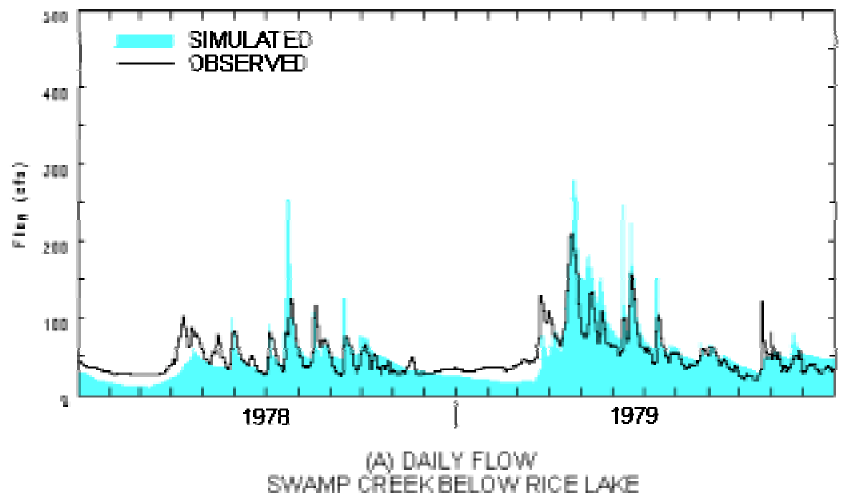


Figure 19. Daily flows observed and simulated with the Hydrological Simulation Program - Fortran for Swamp Creek above Rice Lake at Mole Lake Reservation, Wisconsin, for (A) 1978-1979 and (B) 1980 - 1981.



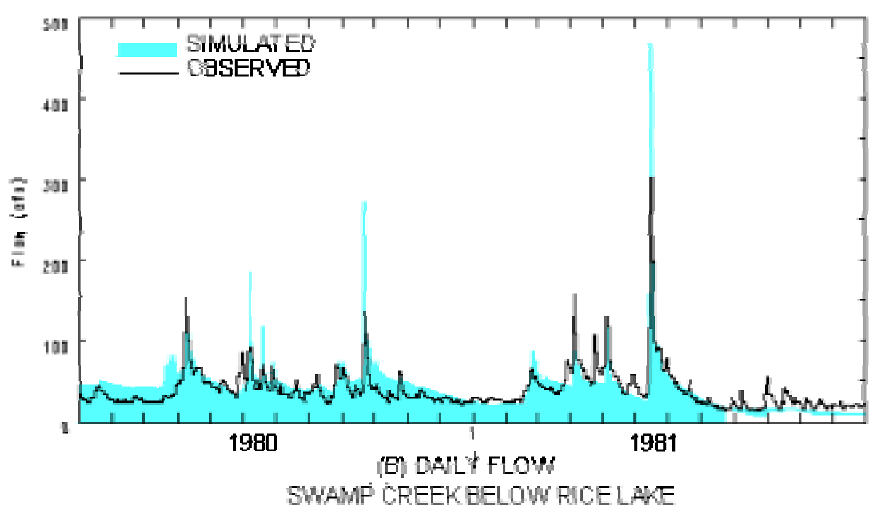


Figure 20. Daily flows observed and simulated with the Hydrological Simulation Program - Fortran for Swamp Creek below Rice Lake at Mole Lake Reservation, Wisconsin, for (A) 1978-1979 and (B) 1980 - 1981.

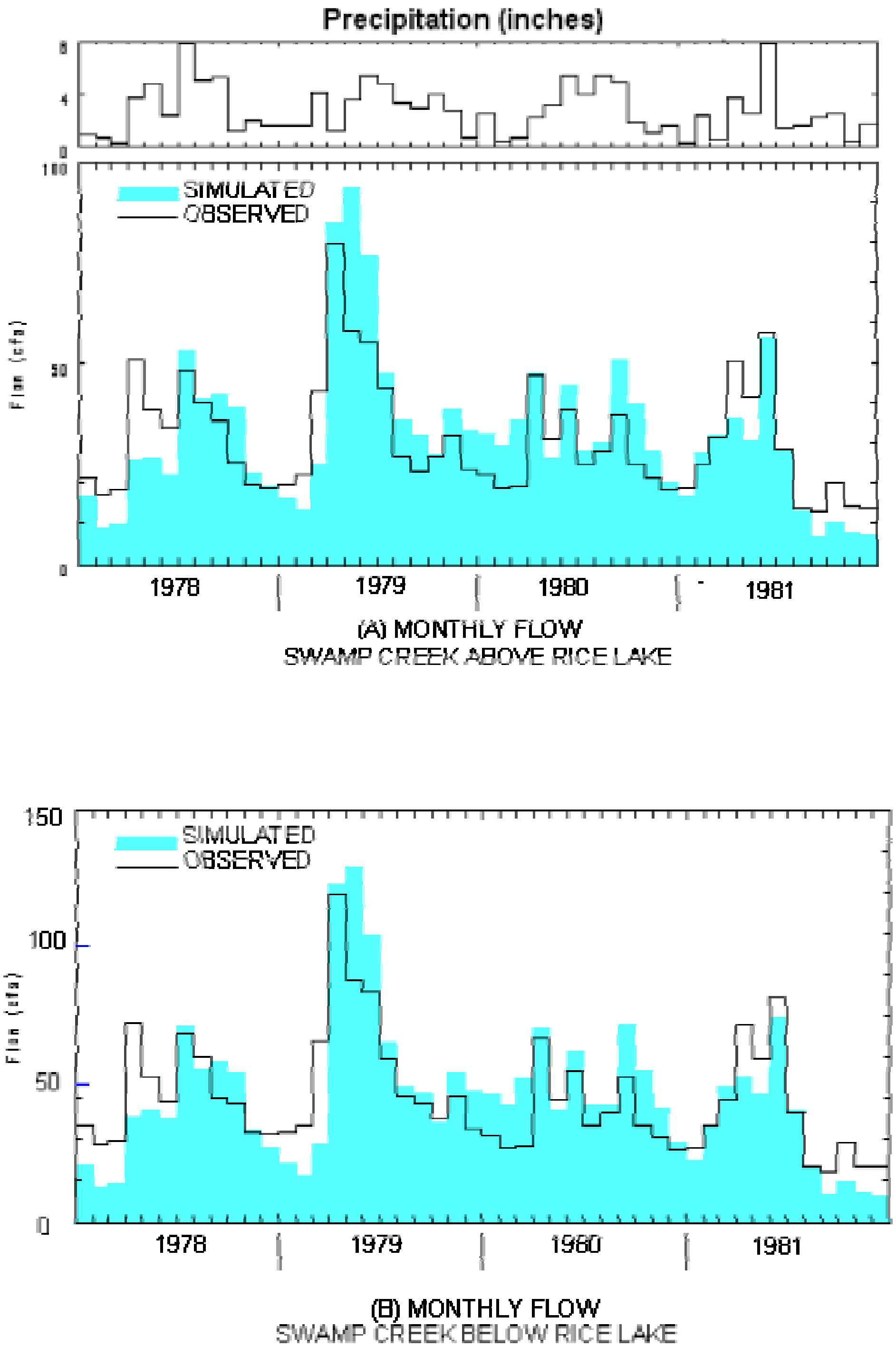
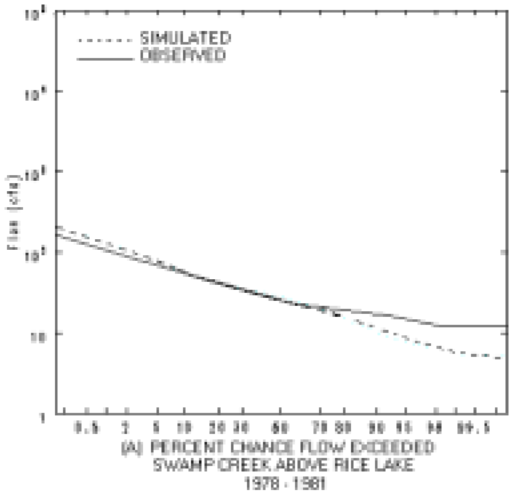


Figure 21. Monthly flows observed and simulated with the Hydrological Simulation Program - Fortran for (A) Swamp Creek above Rice Lake and (B) Swamp Creek below Rice Lake near Mole Lake Reservation, Wisconsin, for 1978 - 1981.



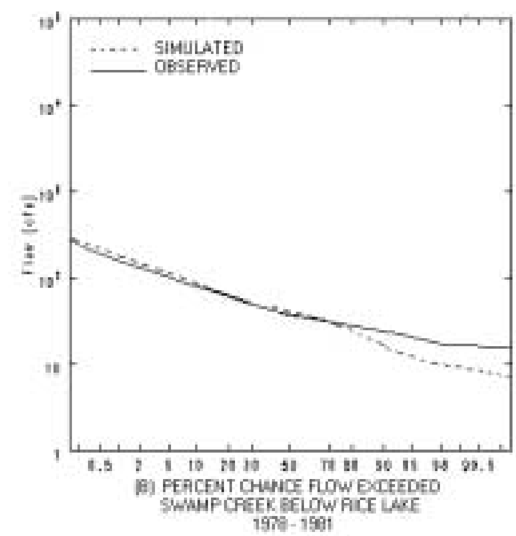


Figure 22. Daily flow duration curves observed and simulated with the Hydrological Simulation Program - Fortran for (A) Swamp Creek above Rice Lake and (B) Swamp Creek below Rice Lake near Mole Lake Reservation, Wisconsin, for 1978 - 1981.

Figures 23 (A) and (B) show results in the Swamp Creek watershed in comparing observed and simulated water-surface elevation for two lakes, Rice Lake and Ground Hemlock Lake in the verification period 1978-1981. The agreement between observed and simulated water-surface elevations for Ground Hemlock Lake is good, but only for a small number of data points. The agreement between observed and simulated water-surface elevations for Swamp Creek is at times very good and at other times very poor. This result is difficult to explain given the reasonable simulation of flows into and out of Rice Lake. Given that the USGS streamflow data are thoroughly quality assured, it seems that some of the water-surface elevation data for Rice Lake may be unreliable.

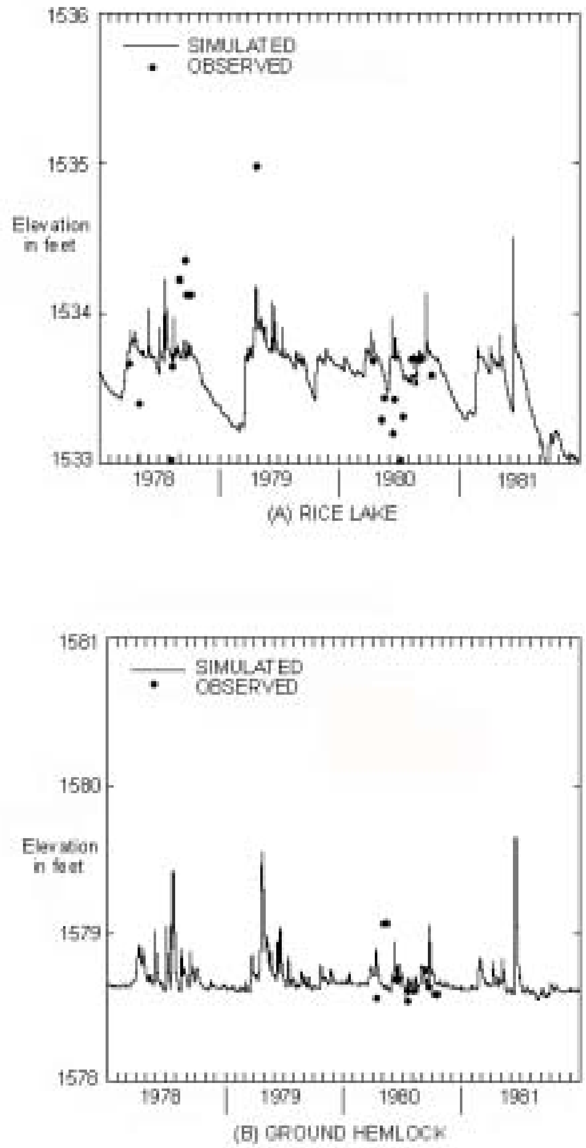


Figure 23. Lake water-surface elevations (stage) observed and simulated with the Hydrological Simulation Program - Fortran for (A) Rice Lake at Mole Lake Reservation, Wisconsin, and (B) Ground Hemlock Lake near Crandon, Wisconsin, for 1978 - 1981.

Pickerel Creek Spatial Verification

Since continuous discharge data are not available for the Pickerel Creek drainage area, verification had to be done by comparing observed lake level and wetland water-level data with simulated results. For the same reason, the statistical programs within HSPEXP could not be utilized. The Pickerel Creek watershed model simulated the period 1971 through 1995 using the best-fit parameter values from Swamp Creek.

Pickerel Creek watershed has a flow duration curve developed by the USGS based on thirteen measurements on Pickerel Creek below Rolling Stone Lake, and correlation with seven measurements on the Wolf River at Langlade. It was felt that the correlation of the 14.7 mi^2 Pickerel Creek watershed with the 462 mi^2 Wolf River watershed was not a sufficiently accurate test for an HSPF model calibrated to 5 years of daily flows in Swamp Creek.

Observed and simulated lake levels within the Pickerel Creek watershed are shown in Figures 24-28 for Rolling Stone, Little Sand, Duck, Deep Hole, and Skunk Lakes, respectively. The solid line on the plots represents the Pickerel Creek watershed simulated baseline using Swamp Creek calibration parameters, and the points are observed data. A quick visual comparison of observed versus simulated water-surface elevations indicates good general agreement. However, there are examples of poor agreement between observed and simulated values. For example, Figure 26(A) shows the poor agreement between observed and simulated water-surface elevations fo Duck Lake in 1985, and Figure 27(A) shows the poor agreement between observed and simulated water-surface elevations for Deep Hole Lake in 1978.

Figures 25, 26(B), 27(B), and 28 illustrate the results of “fitting” of seepage from these lakes as discussed in detail in the section “HSPF Seepage Methodology”, and show the comparison of observed and simulated lake water-surface elevations. Figures for four of the lakes show the entire period during which observations were taken between 1976 and 1995. Because the “fitted” seepage was bounded by the results of previous lake water balance studies by measurement and by simulation with the LAK2 module of MODFLOW, the comparison of observed and simulated stages provides some assurance that HSPF reasonably simulates the rainfall-runoff process in the Pickerel Creek watershed.

The very good agreement between simulated and observed values for Rolling Stone Lake (only four years of observed measurements taken) indicates that the calibrated parameter set is particularly well suited to simulating the rainfall-runoff process at a slightly larger watershed scale (Figure 24). That is, the accuracy of the HSPF simulation improves as the size of the watershed considered approaches that of the calibration watershed. Further, Rolling Stone Lake did not have the same seepage fitting applied to its baseline (for reasons to be discussed later) yet has the very good fit between observed and simulated values.

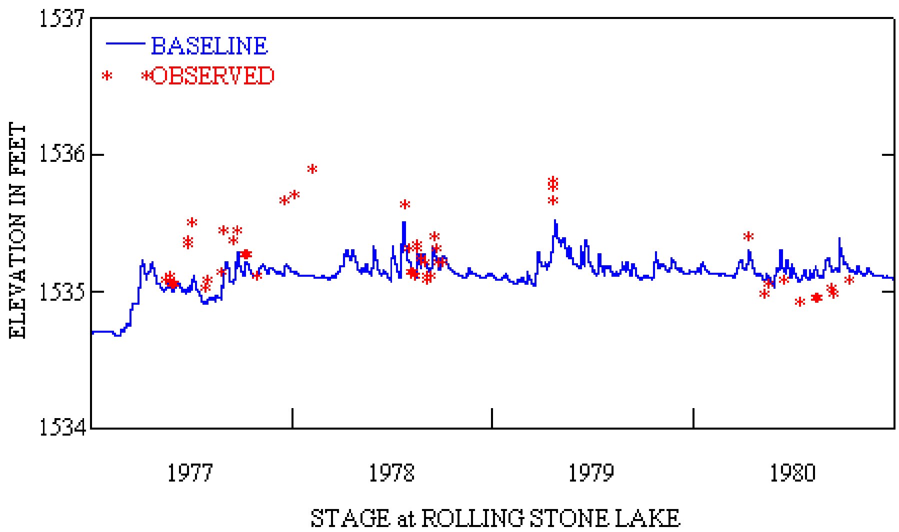


Figure 24. Water-surface elevation observed and simulated with the Hydrological Simulation Program - Fortran for Rolling Stone Lake near Crandon, Wisconsin for 1977-1980.

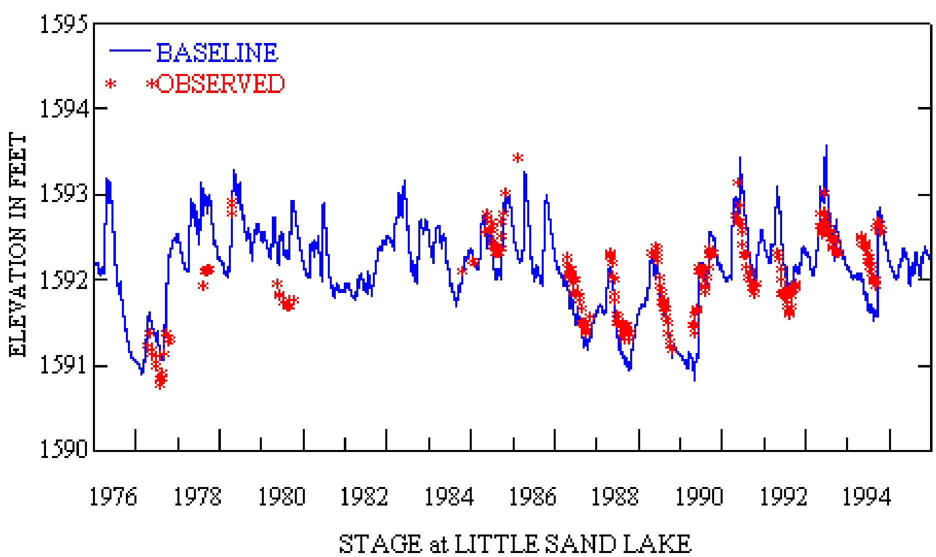


Figure 25. Water-surface elevation observed and simulated with the Hydrological Simulation Program - Fortran for Little Sand Lake near Crandon, Wisconsin, with seepage adjustment for 1976-1995.

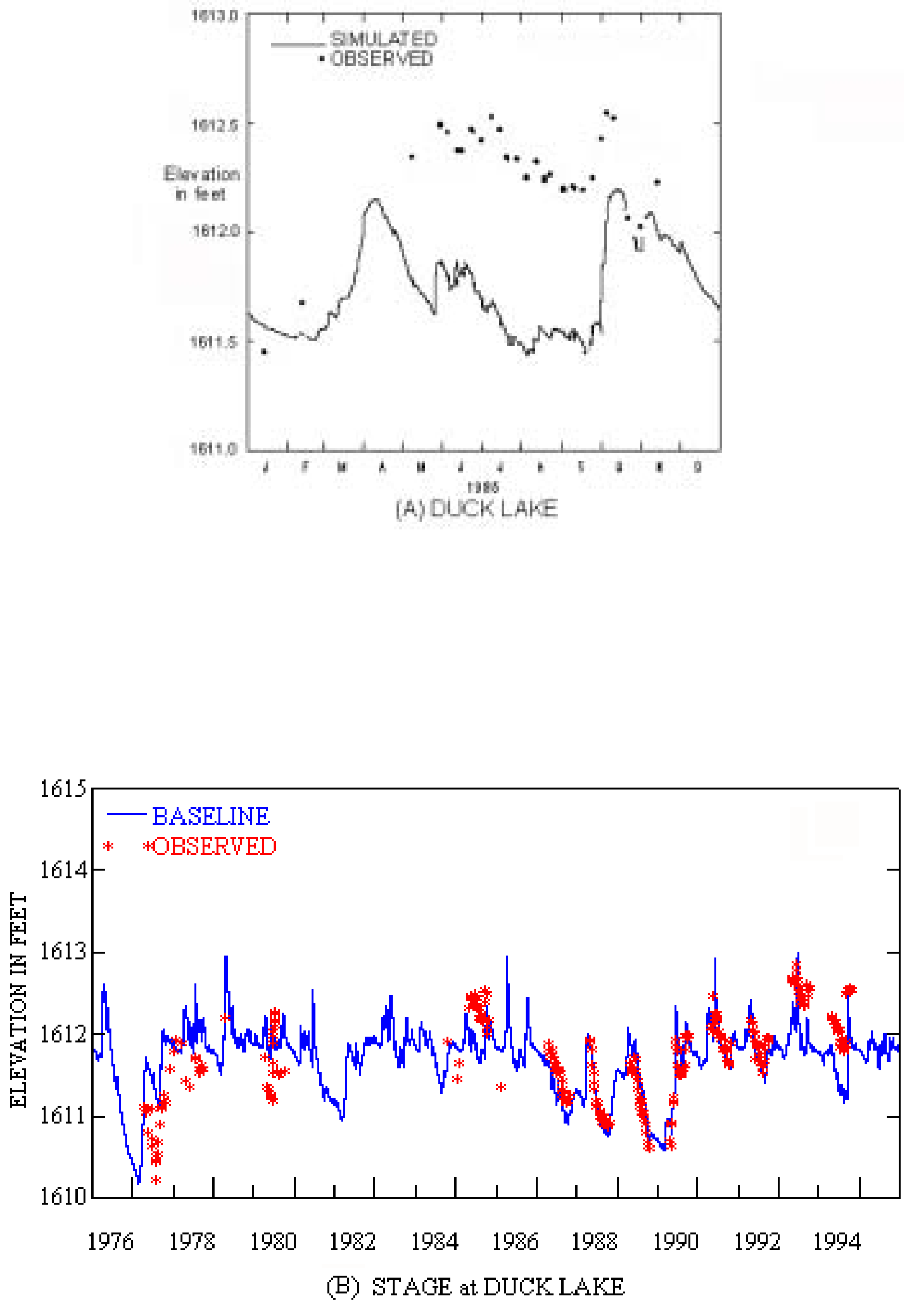
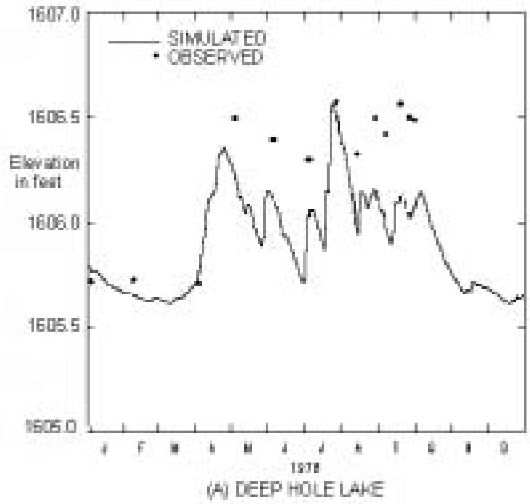


Figure 26. Water-surface elevation observed and simulated with the Hydrological Simulation Program - Fortran for Duck Lake near Crandon, Wisconsin for (A) 1985, and (B) with seepage adjustment 1976-1995.



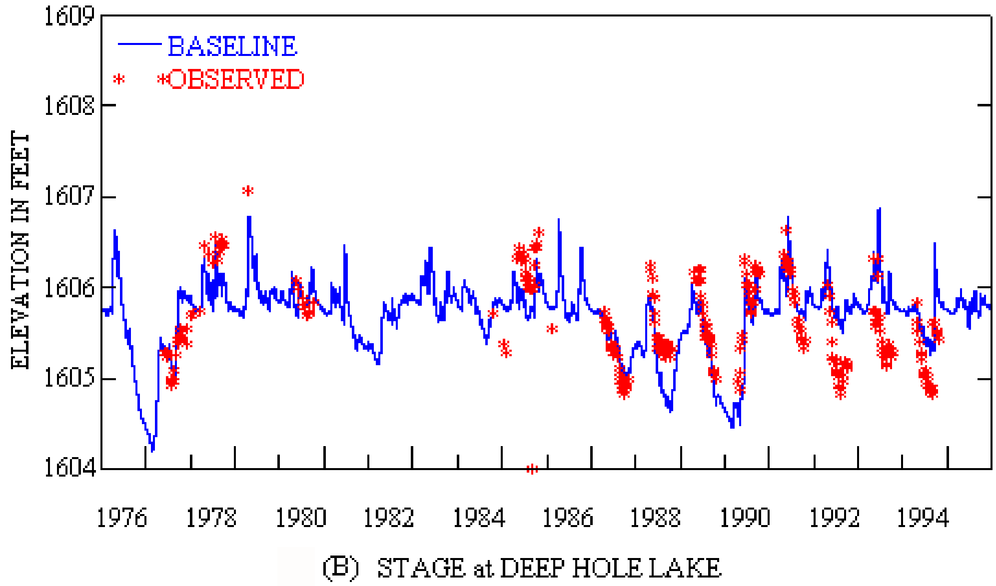


Figure 27. Water-surface elevation observed and simulated with the Hydrological Simulation Program - Fortran for Deep Hole Lake near Crandon, Wisconsin for (A) 1978, and (B) with seepage adjustment 1976 -1995.

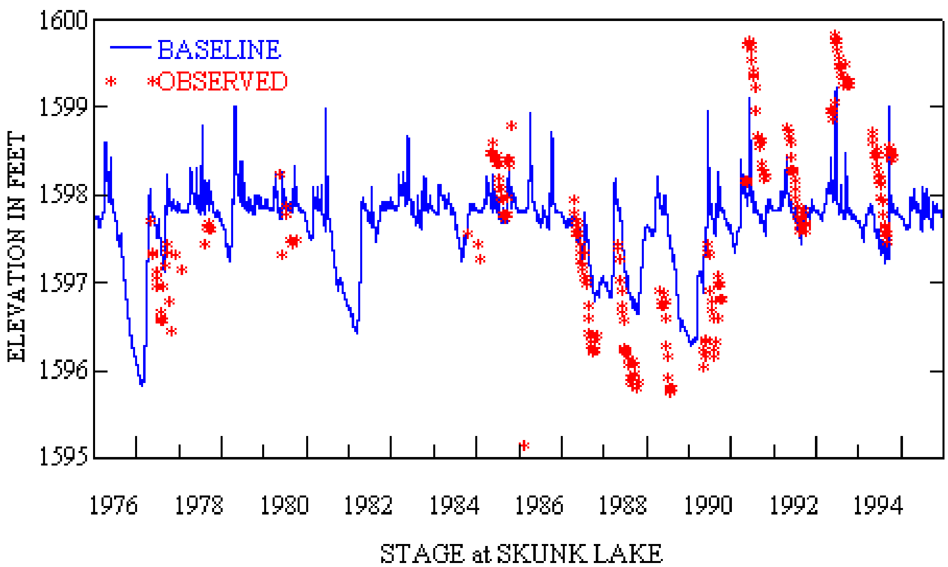


Figure 28. Water-surface elevation observed and simulated with the Hydrological Simulation Program - Fortran for Skunk Lake near Crandon, Wisconsin, with seepage adjustment 1976 -1995.

Summary Comments

Thomann (1982) recommended that a verification data set should represent the system under a sufficiently perturbed condition to provide an adequate test of the model. This criterion was partially met in this study of HSPF applied to the vicinity of the proposed Crandon Mine. The temporal verification period involved substantially reduced annual runoff (approximately 1.1 inches or 10 percent less) than the calibration period. Yet nearly all the HSPEXP fit criteria were met both above and below Rice Lake. Further, while the monthly fit statistics did not achieve all the acceptance levels set forth in the QAPP, these values were not substantially worse than some of the values obtained during calibration. The spatial verification also yielded interesting results. Observed lake levels were matched extremely well in the Pickerel Creek watershed primarily for time periods outside of the1978-1986 verification/calibration periods in Swamp Creek. These good verification results under substantially different conditions from the calibration support the reliability of the HSPF model for simulation of the rainfall-runoff process in the vicinity of the proposed Crandon Mine. Finally, the testing of the HSPF output with respect to measured flow, lake stage, and wetland water levels also provides a thorough evaluation of the usefulness of HSPF for simulation of changes in surface hydrology resulting from the land cover and other changes due to mine construction and operation.

Figure 29 plots the difference (error) between simulated minus observed values in the combined calibration and verification years 1978 - 1986. The data are exhibited to illustrate monthly performance at different times in the year. The greatest over- and undersimulation appears in the spring, especially in April, which is expected due to the seasonal snowmelt that can greatly affect stream discharge measurements. May, June, and July show the greatest oversimulation when outliers are included, but excluding outliers the errors are fairly evenly distributed and not too great. The winter months of November, December, January, and February have the least difference between simulated and observed values.

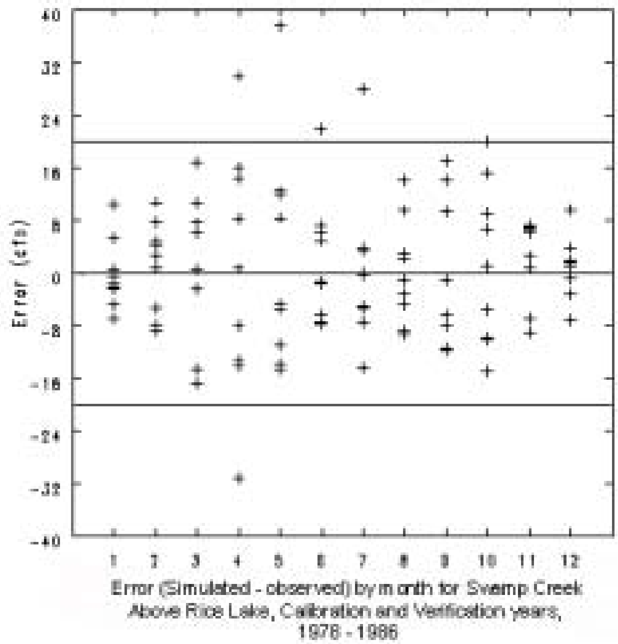


Figure 29. Monthly Error (Simulated - observed) for Swamp Creek above Rice Lake, Calibration and Verification years, 1978 - 1986.

DEVELOPMENT OF SWAMP AND PICKEREL CREEKS SCENARIOS

The HSPF calibration results, supported by the temporal and spatial verification satisfy the criteria stated in the Quality Assurance Project Plan (QAPP) and historical data. Following calibration, HSPF was used to analyze scenarios representing operation of the mine by taking the calibration and verification parameters and generating a new 41-year baseline, incorporating a wide range of measured meteorological input from 1955 through 1995. Since this analysis is based on 41 years of generated values, it included a wide range of potential climate and flow conditions in the watershed, and encompassed the wet, dry, and average conditions that were used as a basis for scenario comparisons for the ground water modeling. The baseline was compared statistically and graphically to two scenarios, defined by choosing two operational pumping rates. The operational pumping rate of 600 gpm is chosen for Scenario 1 based on the pumping rate (monthly rolling average) requested by Nicolet Minerals Company in the Mine Permit Application. The Scenario 2 pumping rate of 1440 gpm reflects a conservative, maximum bounding value based on previous estimates of modeled groundwater inflow to the mine. The comparison of baseline to scenario analyzed the frequency of high flows, low flows, and changing water levels before (without mine) and during the proposed mine operation, then these comparisons will be related to effects on habitat and ecosystems. HSPF does not simulate actual observable events, rather, HSPF results are used to compare relative differences between baseline and scenario(s), not between absolute values or individual numerical results.

In interpreting the results of these simulations, it is important to remember that the calibration and verification of the Swamp Creek and Pickerel Creek watershed models were based upon nine years of observed data from two streamflow gages within the Swamp Creek basin. While as many physical characteristics of each watershed as possible were used (such as soil porosities, land-surface elevations, etc.), other characteristics for which there are little or no observed data were not incorporated into the watershed models. Simulation results indicate that the calibration and verification are good, especially considering the spatial variability of rainfall, as demonstrated by the broad range of model output that was compared to measured data (streamflow, lake water-surface, and groundwater elevations). It is also important to note that watershed models cannot always accurately simulate observed flows and water levels because of data and model deficiencies. However, the inaccuracies due to data deficiencies are much less important in the comparison of scenarios because the same input time-series are used to obtain both the baseline result and the scenario result and the errors in input data effectively cancel each other out in the comparison among baseline and scenarios. Therefore, the relative accuracy of comparing scenarios generally is substantially better than the absolute accuracy of the model to estimate runoff for a selected time period, and the absolute accuracy already has been assessed as good relative to the goals stated in the QAPP.

Sensitivity Analysis

A formal sensitivity analysis often is done as part of modeling studies in an effort to assess the usefulness of the model for decision making and/or the robustness of the conclusions reached from the comparison of baseline and scenario conditions. For example, if under baseline conditions of a natural, unaltered watershed, a wide range of model parameter values results in nearly the same simulated streamflow (an insensitive model), then it is difficult to apply this model to conditions involving an altered watershed because the wide range of model parameters might not be valid for the altered watershed. Conversely, if the model is found to have well identified parameters and the model results are sensitive to the values of these parameters, then the model can be more reliably used for decision making.

In the case of the HSPF model developed for the watersheds potentially affected by the proposed Crandon Mine, the sensitivity of the simulated streamflow to the model parameter values was clearly seen during the 1,600 calibration runs and 200 verification runs. The calibration required matching observed flows at two streamflow gages (above and below Rice Lake) as well as limited lake water-surface elevation and wetland water level data in the Swamp Creek watershed. The verification required matching observed flows during a separate time period in the Swamp Creek watershed as well as limited lake water-surface elevation data in the Pickerel Creek watershed. The requirement to obtain good simulation results at two locations for two time periods sharpened the model parameter identification process. As the final model parameter values were approached, a change to any parameter made one resultant calibration criterion better at the expense of another criterion, or one location or period would achieve a better fit at the expense of another. Thus, the final model parameter values offer a balance among acceptable results at each location and for each time period. The typical sensitivity analysis approach of incrementally increasing each parameter value 25, 50, or more percent and then applying a similar decrease in each parameter value would certainly result in the use of parameter values that are not valid for the Swamp and Pickerel Creek watersheds. Thus, sensitivity analysis was not applied to the parameter values.

The simulation of the changes in the surface water balance resulting from mine construction and operation required assumptions regarding 1) land areas with altered land cover, 2) the pumping rate, and 3) the mine capture zone (area affected by pumping), discussed in later sections “Assumptions” and “Pickerel Creek Watershed Concepts”. The areal extent of the mine site and tailings management area are known, and the capture zone would not be substantially altered by a change in pumping rate (Hunt, 2001, personal communication). Thus, only the pumping rate could be a subject for sensitivity analysis. Therefore, two pumping rates are simulated in this study to provide two endpoints of pumping, and no further attempt to describe the likely variable, true rate of drainage into the mine and subsequent pumping.

Assumptions within HSPF

There are some aspects of modeling that could not be adjusted in fine detail because the changes would not add much predictive value to the model. Assumptions to be noted are:

- Temporal: The mine will not operate for 41 years and simulation does not model what would happen in any particular year of the mine's operation nor does it predict cumulative impacts. The purpose of using a 41-year input time series is to evaluate changes in flows and water levels over as wide a range of naturally occurring input (precipitation, evapotranspiration, etc.) as reasonably as possible. Therefore, flow and water-surface elevation frequency distributions are the focus of the comparison.

- Surface changes: Changes in acreage in the phases of cell development of the TMA would yield a relatively small change when compared to the acreage in the watershed. Thus, the TMA was simulated as if all cells were active simultaneously. This may slightly overstate the impact of the TMA.

- Hydraulic conductivity: HSPF is a surface water model and represents ground water in a very simple way. Therefore, there was no parameter directly comparable to the hydraulic conductivity (permeability) used in groundwater models. One surrogate within HSPF for this property is the seepage restriction applied to water flowing through lake beds. For comparison, the GFLOW analytic element model included "bottom resistance" terms for streams and lakes that were not fully connected to the underlying aquifer (Haitjema and Kelson, 1998). MODFLOW's LAK2 package also included hydraulic conductivity values that restrict flow through lake beds.

- Grout curtain: The mine is an underground feature and as such has no direct impact on the surface water. However, the mine directly impacts ground water and thereby indirectly impacts surface water. As such, the grout curtain is outside the HSPF domain except in the way that the groundwater inflow to the mine calculated by the groundwater models was imposed on the HSPF model. The groundwater calculations included the grout curtain in their simulations.

- Lake mitigation: NMC has presented a plan to mitigate the effects of mine dewatering. The HSPF model did not include any mitigation (except the SAS) because the mitigation plan consists of conditional statements, such as, "if this condition occurs, then mitigation will be implemented". Encoding such detail into the model was beyond the scope of the project.

- Elevation: Each land use and water level within each land segment (PERLND), and stream reach (RCHRES) was represented by a single mean elevation, based on USGS digital elevation models, possibly adjusted to agree with measured lake and/or wetland water-surface elevations. As described in the Quality Assurance Project Plan, the base elevation (BELV) was defined as the bottom of the adjacent stream channel, which, lacking more detailed information, was often set at 2.0 ft below the mean elevation (MELEV) of each of the wetlands. This may affect the uniformity.

- Soil consolidation: if simulation indicates that dewatering causes wetlands in the area to dry out, the storage parameters (e.g., the porosities and upper and lower zone nominal storage) for these PERLNDs could be modified in an attempt to reflect the changes in water capacity caused by consolidation of the soils, but this has not been done. HSPF does not simulate the dewatering-consolidation process.

Swamp Creek Watershed

In constructing the 41-year baseline for the two watersheds, the calibrated and verified parameter set describing the hydrology of the Swamp Creek watershed was used without change for the 41-year Swamp Creek watershed simulation. Hydrologic parameters not related to topography and soils were not changed (see Table 14). However, special considerations were given to seepage and capture zone issues, discussed in detail in the next section.

Table 14. Parameter changes in the Swamp and Pickerel Creek watersheds

Parameters specific to each Watershed		
HSPF Block	**Variable***	**Explanation**
GEN-INFO	List of perlnds	
ATEMP-DAT	ELDAT	elevation data (ft)
SNOW-PARM1	MELEV	mean elevation
PWAT-PARM2	LSUR	overland flow length
	SLSUR	overland flow slope
PWAT-PARM6	MELEV	mean elevation (same values used in SNOW-PARM1)
	BELV	base elevation
	GWDATM	datum for groundwater elevations
	PCW	cohesion water porosity
	PGW	gravitational water porosity
	UPGW	gravitational water porosity in the upper soil layer (= PGW in this model)
GEN-INFO	list of reaches	
HYDR-PARM1	list of reaches/flags	
HYDR-PARM2	FTABNO	FTABLE number
	LEN	reach length (miles)
	DELTH	change in elevation over reach (ft)
	STCOR	stage correction (ft); depth + STCOR = stage
HYDR-INIT	VOL	initial volume of water in reach (acre-ft)
SCHEMATIC		description of hydrologic network
FTABLES	FTABLE	individual for each reach

* Refer to the HSPF Manual for detailed definitions of each of these variables.

Pickerel Creek Watershed Concepts

For the Swamp Creek watershed, it was determined that the nature of the lakes and their seepage characteristics did not require special hydrological consideration within the context of the model, based on information in the EIR and other studies. However, for the Pickerel Creek watershed, the model required fine-tuning in two critical categories, capture zone and seepage. Both were scrutinized and viewed as major conceptual and hydrological components of the modeling effort.

Capture Zone: Groundwater models yield two distinct descriptions of the spatial extent of the mine's impact: the *cone of depression* and the *capture zone* (as shown in Figure 30).

1. The cone of depression is defined as the potentiometric surface that results from the lowering of the groundwater table by the removal of water from an aquifer, usually from a water supply well, but in this case from the proposed Crandon Mine. The cone of depression represents the volume from which water would be removed from groundwater and increases in size over time until the system achieves steady state.

2. In contrast, the capture zone represents the area within which water is diverted from its pre-mine flow paths and flows into the mine. This is the area from which water would be completely removed from the surface water system over the duration of mine pumping, which is the area of interest to a long-term surface water model. This area has been determined by means of particle tracking (Hunt, 1999).

Following discussions with USGS and WDNR groundwater modelers involved in this project, it was decided that the capture-zone area should be used to represent the area from which water is removed by mine dewatering. The particle-tracking results were used to determine the modifications to the capture zone, which then was used to modify the groundwater storage in HSPF. The groundwater model assumes a uniform recharge rate (of approximately 10 inches per year) over the area of the model and includes consideration of the inhomogeneity of the groundwater reservoir. Further discussions with the groundwater modelers indicated that the areal extent of the capture zone would not be significantly affected by the actual pumping rate chosen (i.e., 600 gpm vs. 1440 gpm) and so a single delineation of the capture zone for both pumping rates was used as shown in Figure 30.

Seepage review: Two major points evolved from discussions and review of seepage issues during this project. First, there must be some restriction of flow through some lake bottoms, and second, there is a change of seepage, or an amount of induced seepage, as the influence of mine dewatering lowers the groundwater table beneath the lakes. The lakes in the Pickerel Creek watershed originated as kettles in a glacial terrain, with fine-grained material from the melting ice block comprising the original lake beds. Every core of these lake beds taken by WDNR confirms this composition of glacial origin (Carlson, 2001, personal communication). A not-insignificant amount of loess may also have settled into these lakes (except much or all of Skunk Lake). Therefore, the naturally occurring substrate limits flow through these lake bottoms into the underlying aquifer.

While the lakebeds have been cored and the materials described, seepage from these lakes is not well characterized. The only available measurements were made by NMC in January 1985, published as Appendix I (Range of Potential Seepage from Little Sand, Oak, Duck, and Skunk Lakes) in NMC EIR, Appendix 3.6-9. The seepage was computed by means of a mass balance between gains (precipitation, stream inflow) and losses (evaporation, stream outflow) and attributing the remaining difference in lake

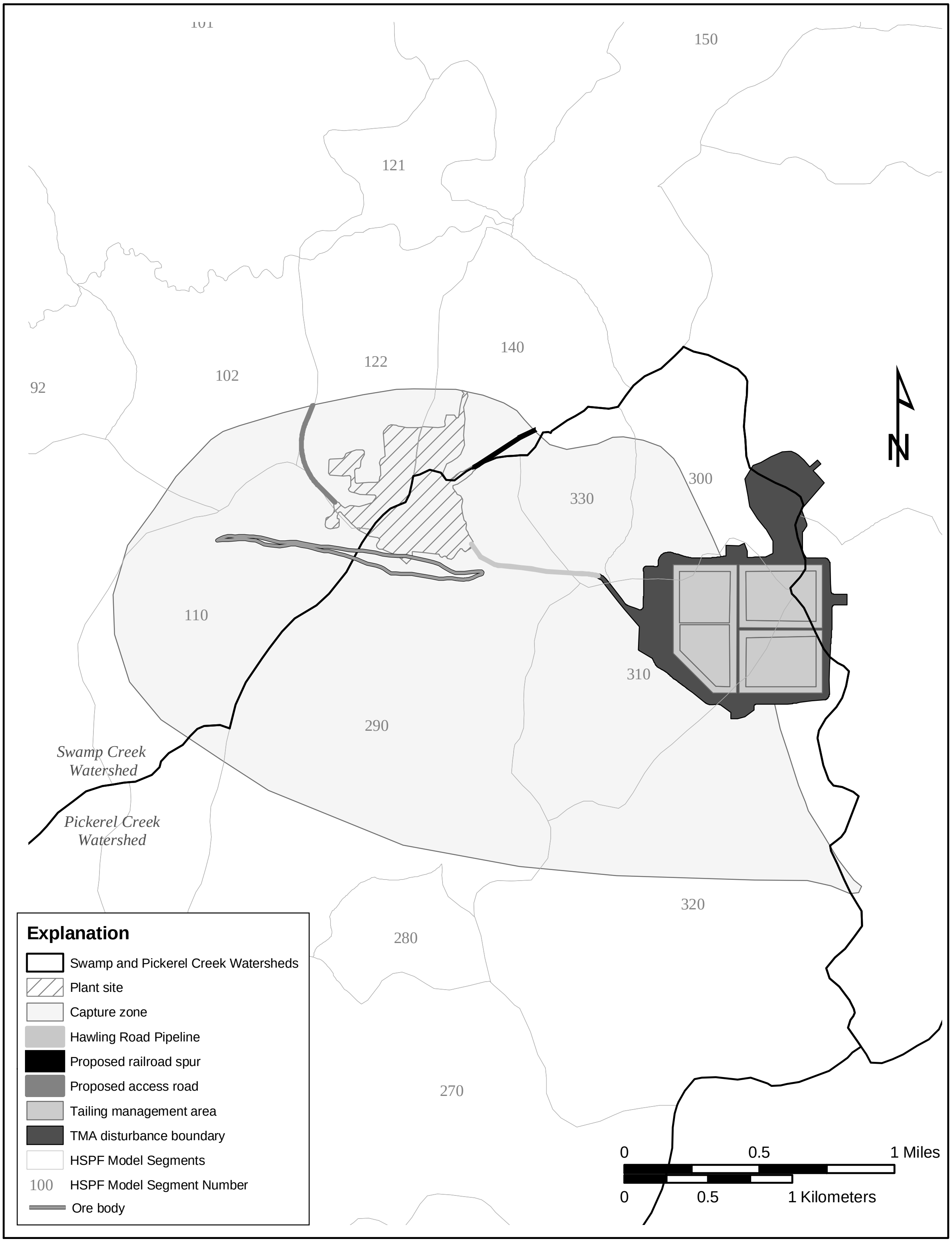


Figure 29. Capture zone overlaid with proposed mine infrastructure and HSPF model segments.

volume to seepage loss. In addition, NMC (1996, revised 1998) published Estimated Water Balance Components for annual water balances for the four lakes listed above plus Deep Hole Lake (summarized in Table 4.2, page 3.6-9-74). The seepage values are all based on short-term (2-3 weeks) studies (including Deep Hole, though data for Deep Hole Lake are not included in NMC's Appendix I).

The analytical element model (GFLOW, Hunt, 1999) describes the lakes with head-dependent flux boundaries (Hunt, 2001, personal communication). Hunt also noted that in the analytic element model, lakes are a small part of the regional water balance affected by the mine and that since the MODFLOW model looked at lakes in more detail, using the Lake Package (LAK2, HSI GeoTrans, 1999), the MODFLOW results provide more information about lake water balances. The LAK2 package models hydraulic conductance through the lake bed as a linear function of the hydraulic conductivity (K) in each cell, divided by the thickness of the lakebed. Flow through the lake bottom is equal to the conductance multiplied by the difference between the elevation of the lake water surface and the groundwater table in cells which are connected to a lake (HSI GeoTrans, 1999, p. 8 and Figure 3).

<u>HSPF Seepage Methodology:</u> A detailed analysis by HSPF modelers yielded little consistency for any of the lakes for estimating seepage when comparing 1) water balance results, 2) LAK2 package results, and 3) initial HSPF modeling results. When comparing results for Little Sand, Duck, Skunk and Deep Hole Lakes, for example, the seepage computed from the water balance versus MODFLOW did not remain in proportion: in two lakes seepage was higher and in two lakes it was lower from one method relative to the other (Table 15). This analysis, combined with sparsely measured and short-term seepage values, and the unreliability of measured seepage values (Winter et al., 1998), led to a decision to back-calculate the seepage for each lake individually, using *observed lake level values for each lake* as the endpoint for calculating seepage values. Seepage in each lake was varied (i.e., calibrated) to minimize the observed and simulated lake level differences (see Figures 25, 26(B) - 28).

Within the HSPF model, the seepage through the lake bottoms was varied as a function of lake depth by values set in a volume-depth-discharge table (FTABLE) for each lake. Variations in seepage with depth were implemented in HSPF in two ways: 1) as the depth of the lake changes and 2) as the area of the lake bed through which water can seep changes. The seepage is varied linearly with depth: thus if lake stage is lower than a reference elevation (initial water-surface elevation), seepage is reduced proportionally and if it is higher, it is increased proportionally. This is an application of Darcy's law using the depth of the water as the head. Similarly, the area of the lake was used as the basis for varying the seepage linearly with lake area. If the area of the lake is less than the basis area (defined as original reference surface area from the Digital Elevation Map), seepage is reduced proportionally and if the area is greater, seepage is increased proportionally. These variations are simplistic but are implemented in this manner due to the absence of data and a more rigorous methodology.

In the fitting of the lake seepage, it was found that for Little Sand and Skunk Lakes, the seepage obtained from the water-balance study yielded good lake level comparison results, and that for Deep Hole Lake the seepage obtained from LAK2 simulations yielded a good result. Further, the fitted seepage values for the other lakes fell within the range of seepage defined by the water-balance study and LAK2 results (see Table 15).

Seepage measurements can be highly variable. Table 15 illustrates this variability as it compares two estimates of seepage in the four Pickerel Creek watershed lakes with results of the HSPF model. The first column lists the seepage results based on the water balance measurements published in the EIR. The second column lists the background seepage calculated by the WDNR (tabulated as GW OUT in the WDNR zinc2a.inl file) converted from ft^3/day to ft^3/sec. The two columns of numbers show only slight consistency: Little Sand Lake always has the highest value and Skunk Lake always has the lowest value, but Deep Hole Lake and Duck Lake alternate between the middle values. Ratios between the entries in these two columns vary from less than 1.0 for Duck Lake and Skunk Lake to greater than 3.0 for Deep Hole Lake and Little Sand Lake.

The HSPF seepage estimates in Table 15 are comparable in some lakes but not in others. Both previous estimate methods had the greatest seepage occurring in Little Sand Lake, but in HSPF seepage is greatest in Deep Hole Lake, followed by Little Sand Lake, Duck Lake, and Skunk Lake. Skunk Lake has the least estimated seepage in all three calculations.

Table 15. Comparison of NMC water balance, WDNR MODFLOW, and HSPF seepage estimates in four lakes within the capture zone in the Pickerel Creek watershed

Lake	Water Balance NMC Seepage (cfs)	Background WDNR Seepage (cfs)	Seepage HSPF (cfs)
Deep Hole	0.12	0.371	0.32
Duck Lake	0.19	0.065	0.10
Little Sand	0.22	0.755	0.23
Skunk Lake	0.07	0.044	0.07

Scenario Implementation in Model Input Files

<u>Scenario Land Cover Changes</u>

The GIS coverage of the mine infrastructure (i.e., the plant, TMA, access road, railroad spur, pipeline, and SAS) was overlain with coverages of the model segments and land cover/land use. The amount of land cover/land use that needed to be converted from the baseline condition to a modified condition, to represent the impacts of surface disturbances in the scenario simulation, was determined by GIS methods. Table 16 shows the total area of each component of the surface infrastructure by land cover and segment. The conversion was accomplished through the following procedure:

First, all of the land in the infrastructure was removed from the model by subtracting the infrastructure areas from the corresponding land cover/land use area factors in the SCHEMATIC block in the Swamp and Pickerel Creek UCI files.

Next, two new land-use categories were added to the model to represent the portion of various infrastructure components that contributes flow to the streams and lakes in the watershed, as described in the EIR, as new pervious and impervious land types. One category was created to represent the disturbed areas adjacent to the TMA (pervious), and the other represents the Plant Site and other infrastructure components (consisting of pervious and impervious fractions), and an assumed impervious fraction for the access road. The remaining area was not included in the model because all runoff from this area is subject to collection because of potential contact with contaminants. The collected runoff from this area is treated and recycled within the mining process system and/or disposed of into the SAS. This area includes the TMA cells, portions of the plant site, and the hauling road/pipeline area.

Table 16. Areas of Land Use/Land Cover converted to other functions in scenario simulation in acres

Infrastructure Component	Segment No.	Forest	Agriculture	Wetland (R)	Wetland (D)	Total
Plant Site	110	2.0	0	0	0	2.0
	120	39.6	0	0	0	39.6
	140	23.0	0	0	0	23.0
	290	51.8	0	0	0	51.8
	Total	116.4	0	0	0	116.4
Access Road	90	0	0.7	0	0	0.7
	100	4.2	0.3	0.3	0.1	4.9
	110	0.2	0	0	0	0.2
	120	2.0	0	0	0.4	2.4
	Total	6.4	1.0	0.3	0.5	8.2
Rail Spur	140	1.7	0	0	0	1.7
	150	3.1	0.3	0	0.7	4.1
	170	0.2	0.6	0	0	0.8
	Total	5.0	0.9	0	0.7	6.6
Hauling Road & Pipeline	290	0.9	0	0.1	0	1.0
	330	0.3	0	0	0	0.3
	Total	1.2	0	0.1	0	1.3
TMA	180	17.1	0	0	0	17.1
	190	21.5	0	2.3	0	23.8
	300	44.1	0	0.3	0	44.4
	310	131.9	0	6.4	0	138.3
	320	48.9	0	8.7	0	57.6
	330	0.4	0	0	0	0.4
	Total	263.9	0	17.7	0	281.6
SAS	150	19.0	60.2	0	0	79.2
	160	0.9	9.9	0	0	10.8
	170	0	0	0	0	0
	Total	19.9	70.1	0	0	90.0

Runoff from the areas representing the actual plant site and TMA was routed to “runoff/detention basins.” Two runoff basins were created, one to represent the aggregate of the runoff basins located in the plant site, and one to represent the runoff basins near the TMA. They are represented in the model as RCHRES segments. The relative areas contributing to each runoff basin and the actual runoff basin sizes and discharge characteristics (i.e., volume-discharge tables) were derived from information in the EIR. The resulting outflow from the aggregated runoff basin was allocated based on the relative area contributing to each actual runoff basin, and this flow was routed directly to the modeled stream or lake located in the model segment which contained the runoff basin.

<u>Scenario Pumping Changes</u>

The pumping of water that drains into the mine that results in a drawdown of the groundwater over the region surrounding the mine was incorporated in HSPF through the capture zone (Figure 30) discussed above. Two pumping rates are considered - 600 gpm (NMC proposed permit limit) and 1,440 gpm (based on the GFLOW model from Hunt (1999) in Table 2a, Mine Inflow Estimates Using Q_{50} Model). A uniform loss of water was assumed over the capture zone such that the loss rate per area is equal to the pumping rate divided by the area of the capture zone (2,223 acres). Based on these pumping rates and the capture zone area, the general removal rate is 0.00143 inches/hour for the groundwater subtraction or 5.20 cubic feet/acre/hour for the lake removal for a pumping rate of 1,440 gpm, and 0.00060 inches/hour or 2.17 cubic feet/acre/hour for a pumping rate of 600 gpm. The capture zone was then overlain in the GIS with the HSPF segment boundaries and the associated pervious land segments or lakes. From this a capture-zone demand was determined for each segment or lake as the product of the area of this HSPF surface feature in the capture zone times the loss rate per area. The capture-zone demands for a pumping rate of 600 gpm and 1440 gpm for each (HSPF) surface feature are listed as removal rates in Table 17 a. Table 17 b shows the results of the removal rates and indicates that under either pumping rate, the natural seepage can satisfy the additional demand on the lakes by pumping in all lakes except for Little Sand Lake. At that location, the demand of 981 gpm at the1440 gpm scenario cannot be met by the 720 gpm seepage. All other values listed indicate that seepage is large enough to satisfy the pumping demands.

For the affected land segments, the capture-zone demands are first removed from the active groundwater storage (AGWS). If the AGWS goes to zero, HSPF computes a groundwater deficit for that PLS. In HSPF, the active groundwater storage essentially is the groundwater above the elevation of the bottom of the water body to which the PLS drains. Thus, AGWS values equal to zero mean that the groundwater table has dropped low enough that baseflow to the water body stops. However, the aquifer can be further depleted below the bottom of the water body. By calculating the groundwater deficit at time step i + 1 as:

$$\text{deficit}(i+1) = \text{deficit}(i) + \text{capture-zone demand} - \text{percolation}$$

(percolation from the upper zone/lower zone interface in Figure 10), the fluctuations in the water table over time hour-by-hour (i to i+1) can be approximated. When the deficit becomes negative, AGWS again starts to fill. A similar procedure was developed and applied successfully by Zarriello and Ries (2000) to simulate the effects of pumping wells near the Ipswich River in Massachusetts, which often experiences zero flows in the summer.

For lakes, if the natural seepage is adequate to meet the capture-zone demand, the natural seepage rate is used unchanged in the lake water-balance simulation. If the natural seepage is not adequate to meet the capture-zone demand, the seepage is increased to meet the capture-zone demand. At first glance, the approach that the natural seepage remains unchanged if it is greater than the capture-zone demand must seem illogical. The water table has dropped because of the drainage to the mine, therefore, the seepage must increase. However, this approach is reasonable within the HSPF simulation of the lake water balance. The water balance for lakes is:

$$\begin{aligned}\text{Volume in Lake}(i+1) = {} & \text{Volume in Lake}(i) + \text{Precipitation}(i+1) - \text{Evaporation}(i+1) \\ & + \text{Runoff}(i+1) - \text{Seepage}(i+1)\end{aligned}$$

In LAK2, the i are years, precipitation and evaporation are representative annual values (mean, wet year, dry year, etc.), runoff is computed by a constant coefficient applied to the representative annual precipitation, and seepage is computed by Darcy's law applied to the lake bed using the lake and groundwater surface elevations to determine the hydraulic gradient. In HSPF, the i are hours, precipitation and evaporation (calculated) are hourly values determined directly from the 41-year time series, runoff is simulated on an hourly basis, and the natural seepage is adjusted as a linear function of water-surface elevation and water-surface area (represented in the FTABLEs in HSPF). The main effect of mine drawdown on the lake water balance in HSPF is the drawdown of the active groundwater storage (AGWS) of the areas draining to the lake. Therefore, the *runoff* is substantially reduced hour-by-hour because of the mine drainage in the HSPF simulation. This effect is not considered in LAK2. The decrease in inflow is considered to be proportional to the likely increase in seepage through the lake bed as both result from the decrease in the water table. Thus, within the approach to simulating the lake water balance applied in HSPF, the effects of groundwater drawdown are appropriately considered.

In summary, two scenarios are considered here. Scenario 1 represents the site during construction and operation, with dewatering occurring at a rate of 600 gpm, using 41 years of generated flow and stage values (corresponding to measured meteorological input from 1955 through 1995). Scenario 2 is the same except that the 1440 gpm pumping rate is used. The model results for each scenario were analyzed and compared to the baseline results to identify the relative changes in the frequency of very low or very high flows and water-surface elevations. Figure 31 shows the locations where HSPF output is compared among the baseline conditions and the scenarios.

Table 17 a. Land use, lake area, and intersecting area of capture zone in the Hydrological Simulation Program - Fortran (HSPF) segments corresponding to 600 and 1440 gpm pumping rates

Model Segment	Land-cover Category	Area (acres)	Capture Zone Area (acres)	AGWS Removal Rate (600 gpm) (inches/hour)	AGWS Removal Rate (1440 gpm) (inches/hour)
80	Forest	735.7	14.6	0.00001	2.84E-05
102	Forest	259.7	61.1	0.000141	3.37E-04
110	Agriculture	5.3	3.4	0.000385	9.23E-04
	Forest	333.8	268.6	0.00048	1.15E-03
	Wetland	36.8	33.0	0.000534	1.28E-03
122	Forest	210.2	57.9	0.000164	3.94E-04
	Wetland	21.0	13.7	0.000389	9.33E-04
140	Forest	163.2	38.6	0.000141	3.39E-04
	Wetland	3.3	3.3	0.000596	1.43E-03
190	Forest	719.9	2.6	0	5.13E-06
270	Forest	997.9	6.6	0	9.39E-06
	Wetland	110.9	1.0	0	1.37E-05
290	Agriculture	17.9	14.4	0.00048	1.15E-03
	Forest	581.9	416.2	0.000434	1.04E-03
	Wetland	134.7	91.5	0.000405	9.72E-04
	Lake (Little Sand)	227.2	188.9		
300	Forest	156.0	42.0	0.000161	3.85E-04
	Wetland	50.6	28.7	0.000339	8.13E-04
310	Forest	165.3	149.9	0.000542	1.30E-03
	Wetland	64.4	73.9	0.000684	1.64E-03
	Lake (Duck)	23.2	26.8		
320	Forest	756.4	236.6	0.000187	4.48E-04
	Wetland	130.5	42.4	0.000194	4.65E-04
	Lake (Deep Hole)	94.2	3.5		
330	Forest	113.3	92.8	0.000488	1.17E-03
	Wetland	9.1	9.1	0.000596	1.43E-03
	Lake (Skunk)	7.6	6.8		
401 *	Plant site, etc.	184.5	123.7	0.0004	9.59E-04
402 *	TMA	282.0	130.3	0.000276	6.61E-04

* Not segment, modification of segment added to model for scenarios representing construction/operation at surface

Table 17 b. Resulting removal rate in the Hydrological Simulation Program - Fortran (HSPF) segments, corresponding to 600 gpm and 1440 gpm pumping rates.

Lake	Potential maximum natural seepage no pumping (ft^3/hr)	Induced seepage due to pumping 600 gpm (ft^3/hr)	Induced seepage due to pumping 1440 gpm (ft^3/hr)
Little Sand Lake	720	409	981*
Duck Lake	234	58	139
Deep Hole Lake	864	7.6	18.4
Skunk Lake	259	14.8	35.5

* Only scenario and location where seepage demands due to pumping are not met

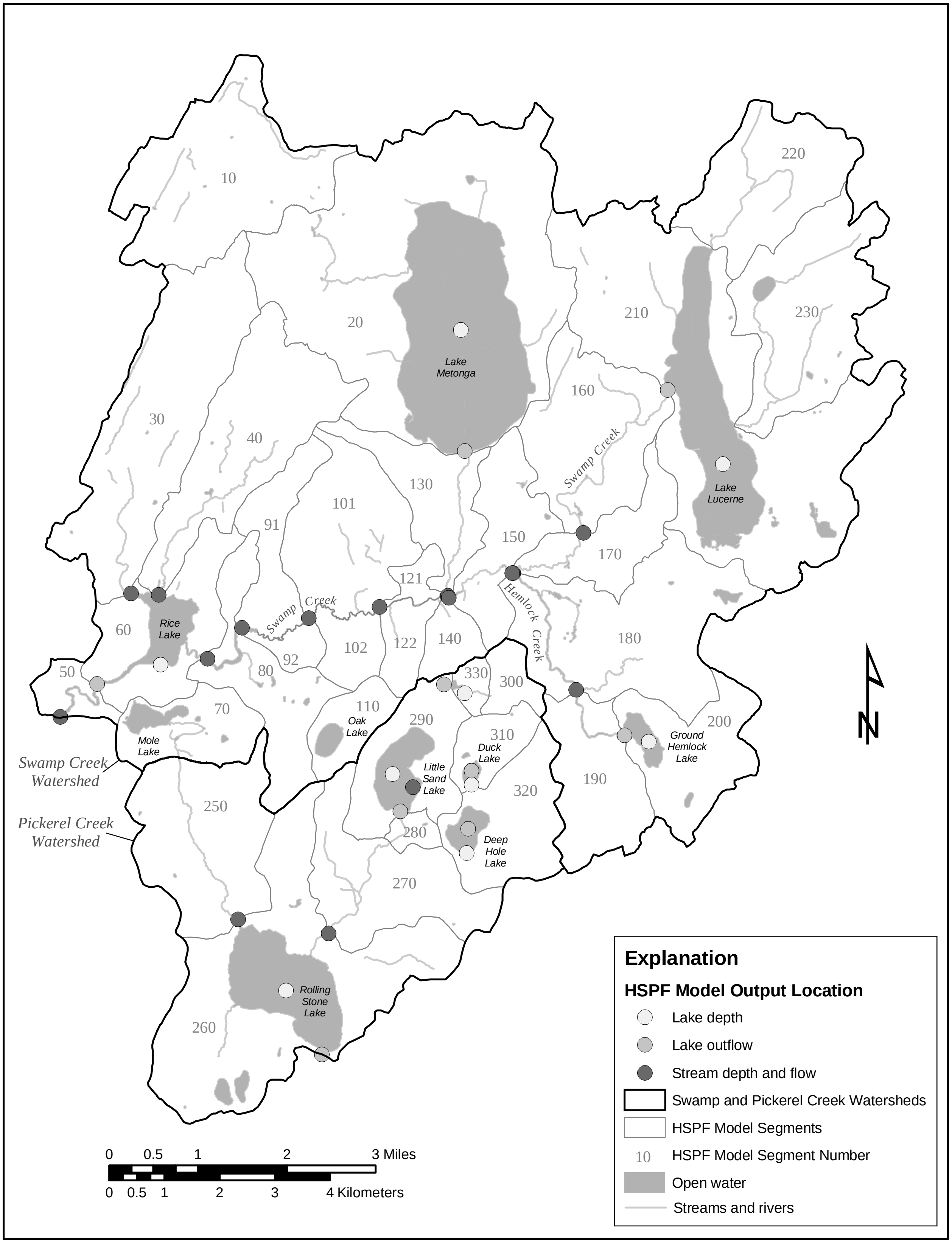


Figure 30. Model output locations used in the comparison of simulation results obtained with the Hydrological Simulation Program - Fortran (HSPF) for baseline and scenario conditions in the vicinity of the proposed Crandon Mine in Wisconsin.

RESULTS OF SCENARIOS

Swamp Creek Watershed Results

The baseline is the output from the model using the same parameter values utilized in achieving the water balance for natural conditions in calibration and verification, using observed hydrological data. Those same parameter values were used for a 41-year simulated baseline using observed meteorological data but does not include observed hydrological data. The model simulation of storms and storm statistics used observed data selected from storm events (including some possible snowmelt influence in high flows events for April) shown in Table 7. The 41-year simulation used 36 storms.

The total 41-year runoff for the Swamp Creek watershed increases about 13 and 31 inches for Scenarios 1 and 2, respectively, when compared to the 41-year baseline. The outputs are shown in Table 18. This increase is attributed to the presence of the SAS reinfiltrating water taken from the mine and reintroduced in Segment 150. Some of this water is taken from the Pickerel Creek subsurface watershed basin and added to the SAS. The total of lowest 50% flows increase 6 and 16 inches in 41 years in Scenarios 1 and 2, respectively. Other increases are more modest or minimal.

A more detailed quantification of the results by segment or by reach better describes what occurs when comparing the 41-year baseline and 41-year scenarios, and begins with Table 20. Most changes occur in the areas closest to the mine north of the ore body and south of Swamp Creek.

<u>Lake and Reach Stages in Swamp Creek Watershed</u>
(Swamp WDM, RCHRES and PLS locations, STAGE)

Because it is anticipated that some of the stakeholders in this project will be reviewing this model in detail, if not actually developing their own scenarios, data in the GENSCN interface are shown in each section heading, including the location/name of the Watershed Data Management (WDM) file. Stage-duration and flow-duration plots represent all 41 years for the baseline and scenarios unless otherwise stated.

The Swamp Creek watershed results presented here represent the watershed segments by reaches (RCHRES) which correspond to one or several segments and one or several Pervious Land Segments (PLS) as listed in Table 19. Segments 10, 70, and 110 are not represented in this table of reaches because there is no surface water body modeled in these segments. Segments 10, 70, and 110 are located in the far northwestern portion the basin, Mole Lake, and Oak Lake, respectively.

The modeled segments which contain lakes in the Swamp Creek watershed are 20, 60, 200, and 210, representing Lake Metonga, Rice Lake, Ground Hemlock Lake, and Lake Lucerne, respectively. The lake and stream stages that show no change (NC) between baseline and scenarios are indicated in Table 20. Figures 32 (A) - (B) are examples of the Gliske Creek (RCHRES 40) and Outlet Creek (RCHRES 130) segments which have stage duration curves with identical baseline and scenario results. Note the baseline never decreases to zero. Plots are not shown for other segments for which No Change was found.

Other reaches of Swamp Creek contributing to Rice Lake (U, M, and L represent upper, middle, and lower portions of Swamp Creek), including tributaries and Gliske Creek, all exhibit very slight increases in maximum stages for the scenarios. However, minimum stages show much greater differences among baseline and scenarios. Figure 33 exhibits increased values in stage duration curves for depth exceeded ~ 90% of the time (low flows) due to water being reinfiltrated into the system through the SAS. The minimum value never reaches a zero baseflow either in the baseline or scenarios, and values increase from 0.04 to 0.20 feet in Reach 120 and from 0.03 to 0.15 feet in Reach 160 when comparing the baseline condition to Scenario 2. Other segments/reaches responding in this manner (i.e., increased stage with each increased pumping rate scenario), but not plotted, are 50, 80, 90, 100, 150, and

Table 18. Comparison of Swamp Creek watershed 41 year baseline and scenario runs

Description	Baseline	Scenario 600 gpm	Scenario 1440 gpm
Total runoff (in.)	349.616	362.7	380.7
Total of highest 10% flows (in.)	109.92	111.2	112.7
Total of lowest 50% flows (in.)	76.376	82.88	92.36
Evapotranspiration (in.)	1158	928.9	928.8
Total storm volume (in.)	18.167	18.37	18.57
Average of storm peaks (cfs)	198.722	200.992	201.916
Baseflow recession rate	0.99	0.99	0.99
Total simulated storm interflow (in.)	97.83	98.2	97.83
Total simulated storm surface runoff (in.)	52.47	52.58	52.47
Summer flow volume (in.)	87.097	90.54	95.1
Winter flow volume (in.)	57.153	60.32	64.97
Summer storm volume (in.)	5.302	5.38	5.45

Table 19. Swamp Creek watershed RCHRES, Segment, and Pervious Land Segment (PLS) delineation

RCHRES corresponds with Segment(s) —>>	Segment corresponds with PLS —>>	PLS
20 (lower Metonga)	20	102 202 302 502 602
30 (tributary to Rice Lake)	30	103 203 503 603
40 (Gliske Creek)	40	104 204 504 604
50 (below Rice Lake)	50	105 205 605
60 (Rice Lake)	60	106 206 606
80 (above Rice Lake)	80/ 110	108 208 508 608/ 111 211 511
90 (Lower Swamp Creek)	91/ 92	109 209 509 609/ 139 639
100 (Middle Swamp Creek)	101/ 102	110 210 510 610/ 140 540 640
120 (Upper Swamp Creek)	121/ 122/ 140	112 612/ 142 542 642/ 114 214 514 614
130 (Outlet Creek)	130	113 213 513 613
150 (Swamp Creek at Outlet Creek confluence)	150	115 215 515 615
160 (Swamp Creek below Lake Lucerne)	160	116 216 616
170 (Swamp Creek at Hemlock Creek confluence)	170	117 217 517 617
180 (Lower Hemlock Creek)	180	118 218 518 618
190 (Hemlock Creek below Ground Hemlock Lake)	190	119 219 519 619
200 (Ground Hemlock Lake)	200	120 220 520 620
210 (Lake Lucerne)	210/ 220/ 230	121 221 521/ 122 222 522/ 123 223 523

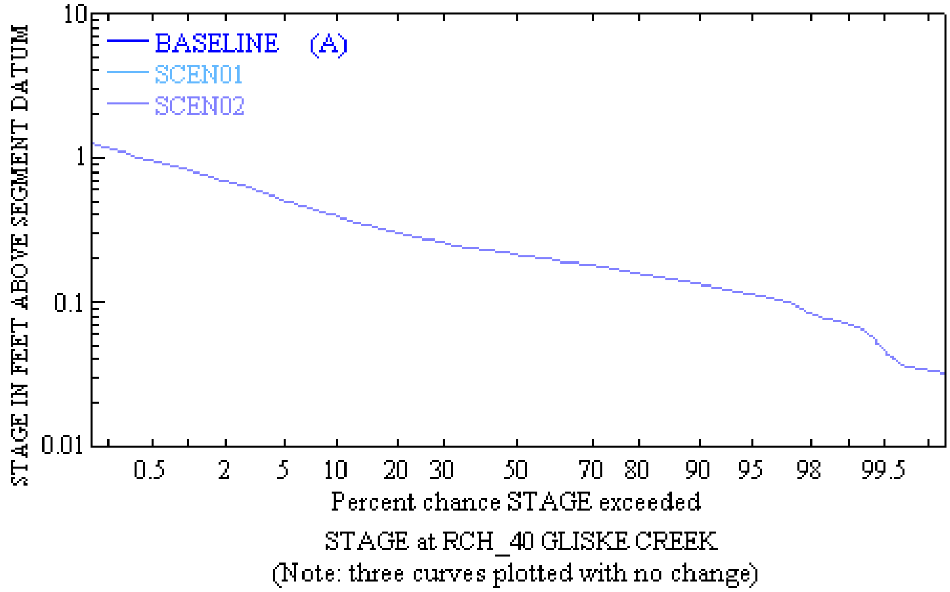
170, which represent stream segments flowing toward Rice Lake in Swamp Creek and downstream from the SAS.

Segments 180 (lower Hemlock Creek) and 190 (Hemlock Creek below Ground Hemlock Lake) are upstream of the SAS and their tributary areas intersect the capture zone. Thus, as listed in Table 20, the minimum and mean stages in feet for these segments are decreased for the scenarios relative to baseline in response to the groundwater depletion in the capture zone (additional decimal places in some segments to illustrate negligible changes).

Table 20. Swamp Creek watershed Stages resulting from baseline and scenarios by segment (600 gpm and 1440 gpm are Scenarios 1 and 2, respectively)

Segment	**Stage Maximum in feet ***			**Stage Minimum in feet ***			**Stage Mean in feet ***		
	Baseline	Scen 1	Scen 2	Baseline	Scen 1	Scen 2	Baseline	Scen 1	Scen 2
20 (lower Metonga)	1606.3	NC	NC	1604.1	NC	NC	1605.1	NC	NC
30 (trib. to Rice Lk.)	3.97	NC	NC	0.14	NC	NC	1.06	NC	NC
40 (Gliske Creek)	1.99	NC	NC	0.03	NC	NC	0.25	NC	NC
50 (below Rice Lk.)	8.76	NC	NC	0.14	0.26	0.37	1.34	1.37	1.4
60 (Rice Lake)	1535.3	NC	NC	1532.6	1532.59	1532.59	1533.4	NC	NC
80 (above Rice Lake)	8.32	8.31	8.31	0.13	0.32	0.48	1.57	1.61	1.67
90 (Lower Swamp Creek)	5.38	5.37	5.37	0.08	0.22	0.32	0.92	0.95	0.98
100 (Middle Swamp Creek)	5.67	5.65	5.66	0.08	0.23	0.34	0.95	0.98	1.02
120 (Upper Swamp Creek)	3.22	3.22	3.23	0.04	0.13	0.2	0.58	0.6	0.63
130 (Outlet Creek)	2.805	2.81	2.81	0.03	NC	NC	0.67	NC	NC
150 (Swamp Creek at Outlet Creek)	5.33	5.37	5.39	0.07	0.25	0.38	0.97	1.03	1.1
160 (Swamp Creek below Lake Lucerne)	2.34	2.35	2.35	0.03	0.1	0.15	0.59	0.6	0.62
170 (Swamp Creek at Hemlock Creek)	4.42	4.43	4.44	0.06	0.16	0.24	1.05	1.07	1.1
180 (Lower Hemlock Creek)	4.32	4.36	4.36	0.06	0.059	0.057	0.629	0.628	0.626
190 (Hemlock Creek below Ground Hemlock)	3.08	3.07	3.07	0.041	0.039	0.037	0.454	0.452	0.451
200 (Ground Hemlock Lake)	1579.7	NC	NC	1578.3	NC	NC	1578.7	NC	NC
210 (Lake Lucerne)	1646.4	NC	NC	1644.7	NC	NC	1645.5	NC	NC

* Above segment datum (BELEV) in HSPF



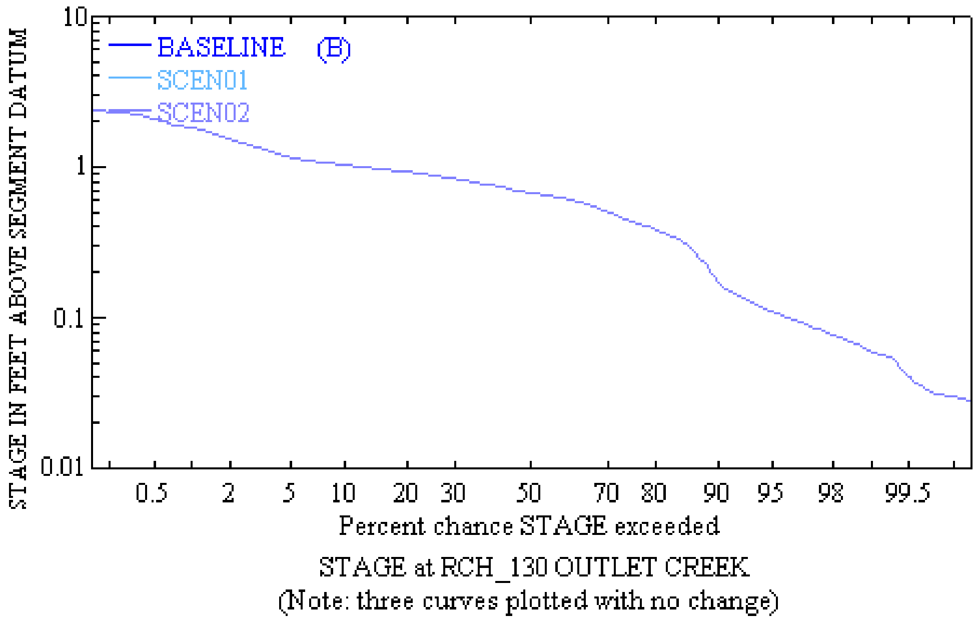
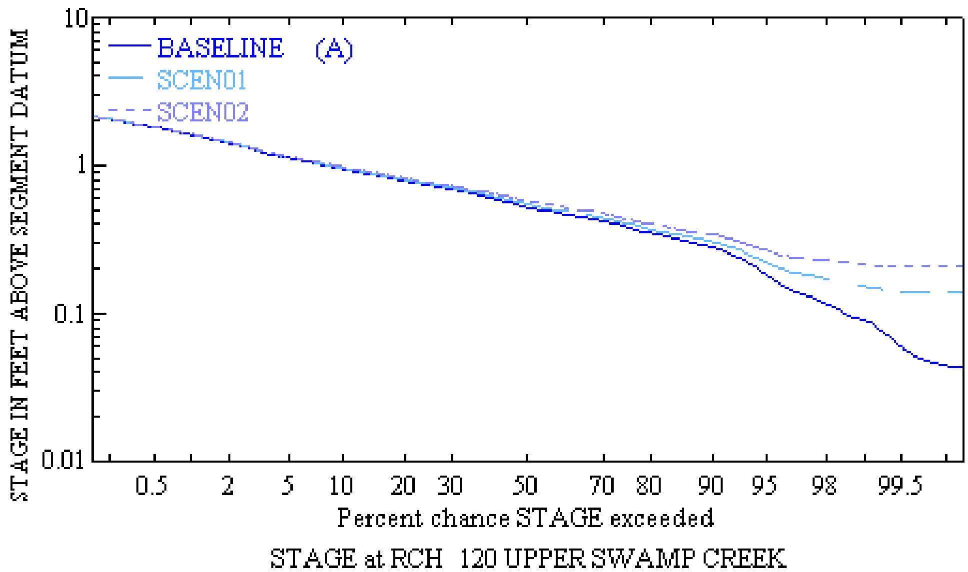


Figure 32. Stage-duration curves for 41-year simulation made with the Hydrological Simulation Program - Fortran for baseline conditions and Scenarios 1 and 2 for (A) Gliske Creek and (B) Outlet Creek.



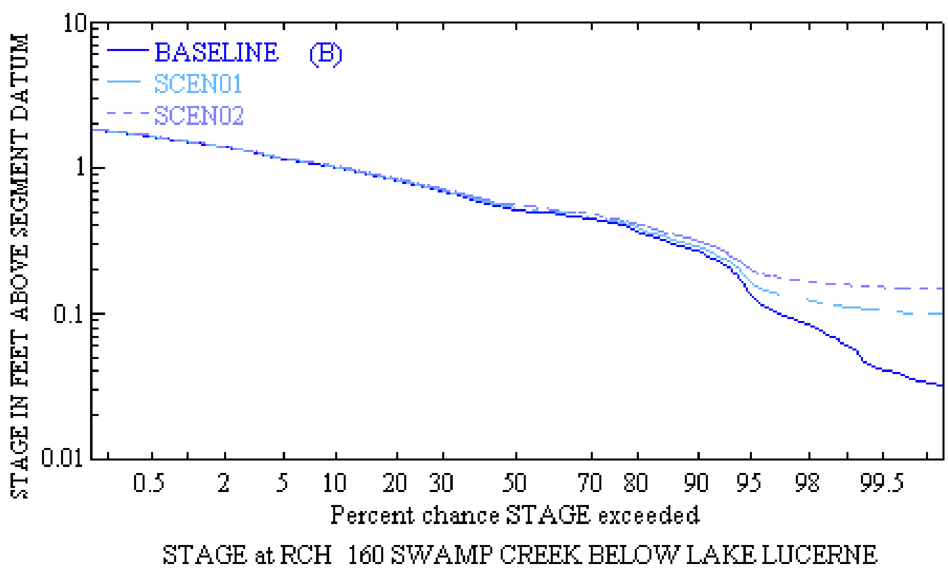


Figure 33. Stage-duration curves for 41-year simulation made with the Hydrological Simulation Program - Fortran for baseline conditions and scenarios 1 and 2 for (A) Upper Swamp Creek and (B) Swamp Creek below Lake Lucerne.

Stream Flows
(Swamp WDM, FLOW)

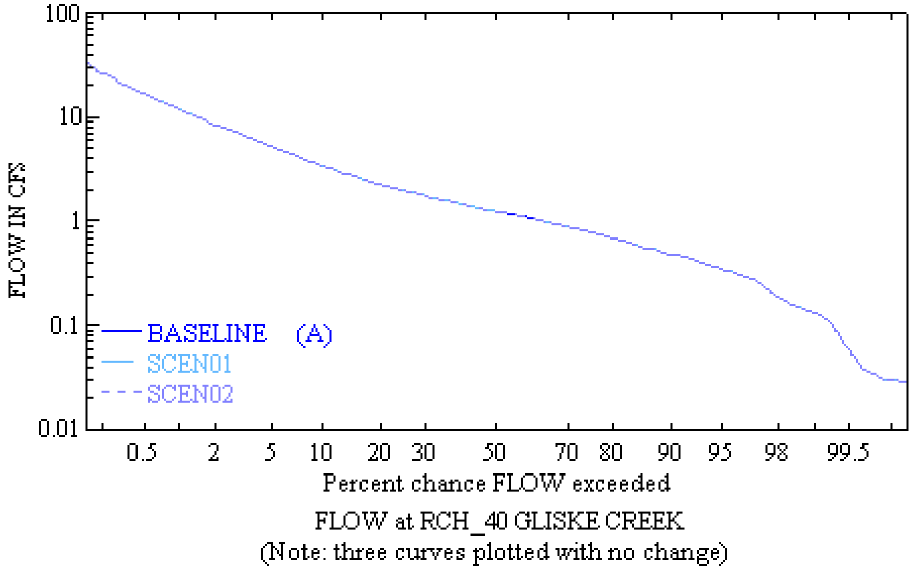
Flow-duration curves for Gliske Creek in Segment 40 and Outlet Creek in Segment 130 show no difference between the baseline and Scenario 1 or 2 (Figure 34(A) - (B)), reflecting the results of stage duration in these segments. Segment 120 Upper Swamp Creek, and Segment 160 Swamp Creek below Lake Lucerne in Figure 35 (A) - (B), exhibit higher flows in the scenarios relative to the baseline as a result of the effective transfer of water to Swamp Creek through the SAS.

Rice Lake in Segment 60 shows an increase in the minimum and mean flows for the scenarios in Table 21, but shows virtually no change in minimum and mean stage. Mean and minimum flows increase in Reaches 50, 60, 80, 90, 100, 120, 150, 160, and 170 in the same manner as the stage increases in the other segments, with negligible changes in flow maximums but flow minimums increasing. Again this is attributed to the reinfiltration of water through the SAS. For Segment 120 the minimum flow increases from 0.1 to 2.8 cfs when comparing the baseline to Scenario 2; for Segment 160, the minimum flow increases from 0.0 to 0.6 cfs when comparing the baseline to Scenario 2.

Segments 180 (lower Hemlock Creek) and 190 (Hemlock Creek below Ground Hemlock Lake) are upstream of the SAS and their tributary areas intersect the capture zone. Thus, as listed in Table 21, the minimum and mean flows for these segments experience a negligible decrease for the scenarios relative to the baseline simulation (non-significant decimal places are shown for illustrative purposes).

Table 21. Swamp Creek watershed Flows resulting from baseline and scenarios by segment (600 gpm and 1440 gpm are Scenarios 1 and 2, respectively)

Segment	Flow Maximum in cfs			Flow Minimum in cfs			Flow Mean in cfs		
	Baseline	Scen 1	Scen 2	Baseline	Scen 1	Scen 2	Baselin e	Scen 1	Scen 2
20 (lower Metonga)	54.3	NC	NC	0	NC	NC	5.9	NC	NC
30 (trib. to Rice Lk.)	137	NC	NC	0.2	NC	NC	8.5	NC	NC
40 (Gliske Creek)	73.4	NC	NC	0	NC	NC	1.9	NC	NC
50 (below Rice Lk.)	783	783	782.9	0.4	1.5	3.1	38.2	39.2	40.5
60 (Rice Lake)	761.2	760.9	760.7	0.4	1.5	3	37.3	38.2	39.6
80 (above Rice Lake)	525.5	524.7	524.7	0.2	1.3	2.8	25.9	26.8	28.2
90 (Lower Swamp Creek)	459.1	458.3	458.2	0.2	1.2	2.8	24.4	25.4	26.8
100 (Middle Swamp Creek)	429.4	428.5	428.4	0.2	1.2	2.8	23.5	24.5	25.9
120 (Upper Swamp Creek)	360	359.6	360.4	0.1	1.2	2.8	21.7	22.8	24.2
130 (Outlet Creek)	80.3	NC	NC	0	NC	NC	6.8	NC	NC
150 (Swamp Creek at Outlet Creek)	254	257.4	259	0.1	1.2	2.8	14.2	15.3	16.8
160 (Swamp Creek below Lake Lucerne)	87.6	87.8	88.1	0	0.3	0.6	8.3	8.5	8.9
170 (Swamp Creek at Hemlock Creek)	113.7	114	114.3	0	0.3	0.7	9	9.3	9.7
180 (Lower Hemlock Creek)	122.4	122.6	122.5	0.037	0.036	0.034	4.223	4.218	4.202
190 (Hemlock Creek below Ground Hemlock)	52.9	52.532	52.522	0.014	0.014	0.012	2.058	2.043	2.037
200 (Ground Hemlock Lake)	17.3	NC	NC	0	NC	NC	1	NC	NC
210 (Lake Lucerne)	40.6	NC	NC	0	NC	NC	6.7	NC	NC



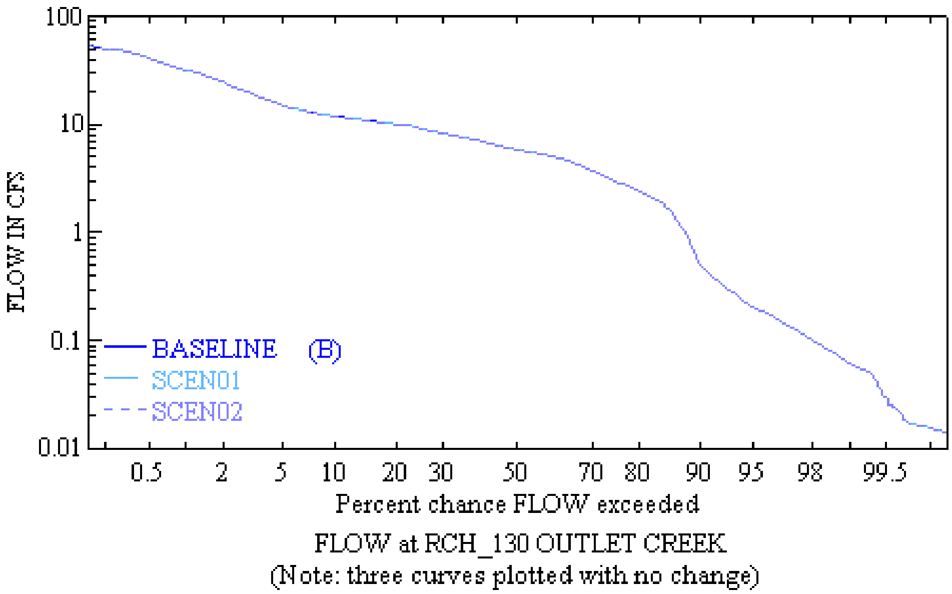
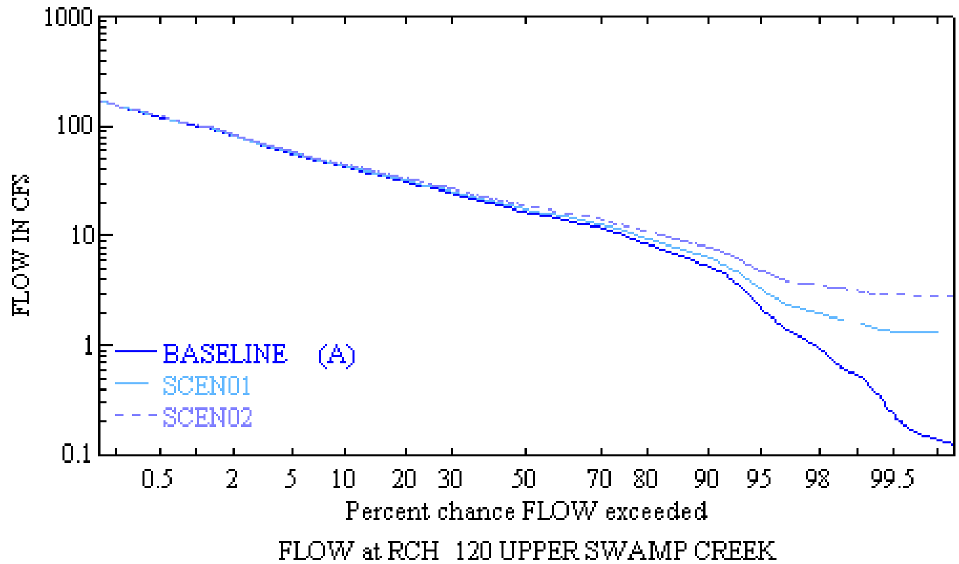
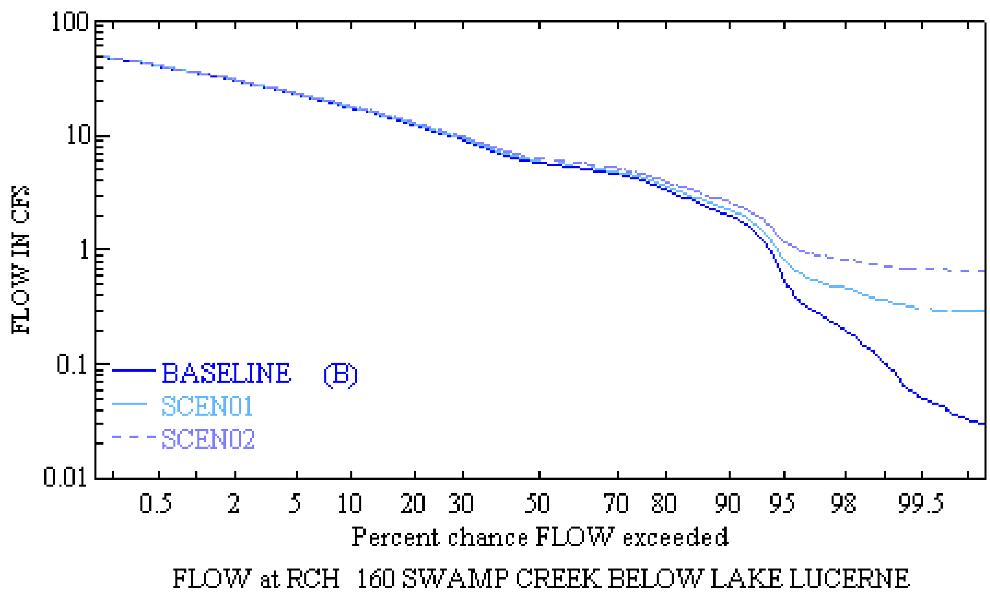


Figure 34. Flow duration curves for 41-year simulation made with the Hydrological Simulation Program - Fortran for baseline conditions and Scenarios 1 and 2 for (A) Gliske Creek and (B) Outlet Creek.





Figu
re 35. Flow-duration curves for 41-year simulation made with the Hydrological Simulation Program - Fortran for baseline conditions and Scenarios 1 and 2 for (A) Upper Swamp Creek and (B) Swamp Creek below Lake Lucerne.

The groundwater deficit resulting from the pumping of groundwater from the mine is computed for the scenarios (Swamp.WDM, location PLS, GWDEFCT, Standard Plots). There are nine Pervious Land Segments (PLS) in the WDM file 108, 114, 119, 140, 142, 211, 214, 401, and 402 that are subject to groundwater deficits. The groundwater baseline condition is not included in the comparison because it has no deficit. Details of the groundwater deficit were discussed previously in the section "Scenario Implementation in Model Input Files/ Scenario Pumping Changes".

Wetlands
(Swampgwel WDM, PLS location, GWEL)

Table 22 lists a summary of modeled wetland segments within the capture zone in the Swamp Creek watershed. There are many segments which have no change when comparing baseline to scenarios because they are not in the capture zone or near the SAS, and these are not listed in this report. As seen previously in other results in this watershed, the changes that do occur in maximum elevation are small; however, there are some significant changes in minimum elevation values. A difference in the results not seen previously is that the scenarios show a *decrease* in water levels in each scenario rather than an increase which had previously been accounted for by the reinfiltration of water through the SAS. Figure 36 provides an example, showing baseline and scenario wetland water levels for Segment 140, for the entire 41 years. Most other segments exhibit smaller decreases; this is attributed to the close proximity of Segment 140 to the mine. Changes in wetland water level maximum values are negligible. Changes in minimum elevations range from 0.0 to 0.7 feet in Scenario 1, and from 0.0 to 4.1 feet in Scenario 2.

Table 22. Groundwater Elevation (GWEL) in the Swamp Creek watershed Recharge (Rech) and Discharge (Disc) Wetlands comparison between baseline and scenarios (600 gpm and 1440 gpm are scenarios 1 and 2, respectively)

Wetland	**Maximum elevation in feet**			**Minimum elevation in feet**			**Mean elevation in feet**		
PLS	**Baseline**	**scen 1**	**scen 2**	**Baseline**	**scen 1**	**scen 2**	**Baseline**	**scen 1**	**scen 2**
511 Rech Seg. 110	1638.7	NC	NC	1636.1	1635.8	1635	1637.4	1637.2	1636.9
514 Rech Seg 140	1627.4	1627.3	1627.2	1625	1624.3	1620.9	1625.9	1625.5	1624
515 Rech Seg 150	1593.1	1593	1593	1590.8	NC	NC	1591.5	NC	NC
519 Rech Seg 190	1650.6	NC	NC	1648.1	NC	NC	1649.1	1649.2	1649.2
540 Rech Seg 102	1597	NC	NC	1594.4	1594.2	1594.1	1596.1	1595.9	1595.5
542 Rech Seg 122	1624.7	1624.6	1624.6	1622.1	1621.8	1620.9	1623.4	1623	1622.4
614 Disc Seg 140	1586.4	1586.3	1586.3	1584	1583.9	1583.8	1584.8	1584.7	1584.6
640 Disc Seg 102	1553.4	1553.3	1553.3	1550.9	1550.9	1550.8	1551.9	1551.8	1551.7
642 Disc Seg 122	1567.3	NC	NC	1564.9	1564.8	1564	1565.8	1565.7	1565

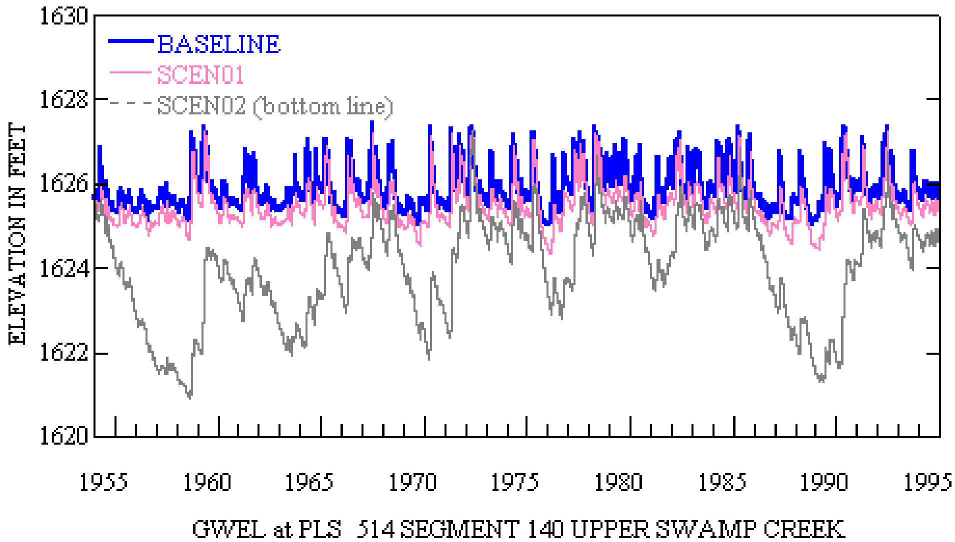


Figure 36. Wetland water-surface elevation computed with the Hydrological Simulation Program-Fortran for a hypothetical 41-year period (driven by 1955 - 1995 data) for baseline conditions, Scenario 1 (600 gpm pumping), and Scenario 2 (1440 gpm pumping) for wetlands in the Upper Swamp Creek drainage.

Pickerel Creek Watershed Results

The Pickerel Creek baseline, which had been computed using the calibrated Swamp Creek HSPF parameters, was adjusted for the 41-year baseline to include the seepage calibrations previously described (i.e. through the process of back-calculation of seepage to observed lake water-surface values). The with-mine scenarios then were simulated by 1) applying surface changes to the appropriate model segments; 2) overlaying the capture zone with the model segments and appropriately removing water from the active groundwater zone in HSPF; and 3) tracking groundwater deficits. This process was applied to Deep Hole, Duck Lake, Little Sand Lake, and Skunk Lake because of their location within the capture zone. Rolling Stone Lake was not directly affected by this process because it is not within the capture zone; however, it was indirectly affected because much of its watershed is in the capture zone. The results for Rolling Stone Lake are shown in the tables, but are not plotted because the graphed values show little difference among baseline and scenarios.

In both baseline and scenario runs, lake water-surface elevations, residual values, stream flow, and lake outlet flow changes are included in the Pickerel Creek watershed model outputs. Residual values are defined as the scenario value minus the baseline value.

<u>Lake Stage in Pickerel Creek Watershed</u>
(Pick_out.wdm, Lakes Location, STAGE or SEEPAGE)

Table 23 lists the pervious land surfaces and the corresponding segments where they are located within the Pickerel Creek watershed. Table 24 lists changes in the maximum, minimum and mean lake water-surface elevation for the baseline and Scenarios 1 and 2 (600 gpm and 1440 gpm pumping rates, respectively) for 41 years. Rolling Stone Lake shows little change and is not considered further. Little Sand Lake and Duck Lake have the greatest change among the lakes at a decrease of 2.2 feet when comparing baseline to scenario minimum values at the 600 gpm pumping rate. Deep Hole Lake and Skunk Lake decrease 0.9 and 1.2 feet, respectively. Table 24 lists greater change in minimum water-surface elevation at the 1440 gpm pumping rate. Again the greatest changes are to Little Sand Lake and Duck Lake with decreases of 3.5 and 4.0 feet, respectively. Also note that Deep Hole Lake decreases 4.5 feet in minimum water-surface elevation. The shaded portions of the table indicate those lakes that are plotted in Figures 37 (A), (B), (C), and (D). These plots show daily water-surface elevation changes for four of the lakes. These figures are not a direct plot of the tabular data.

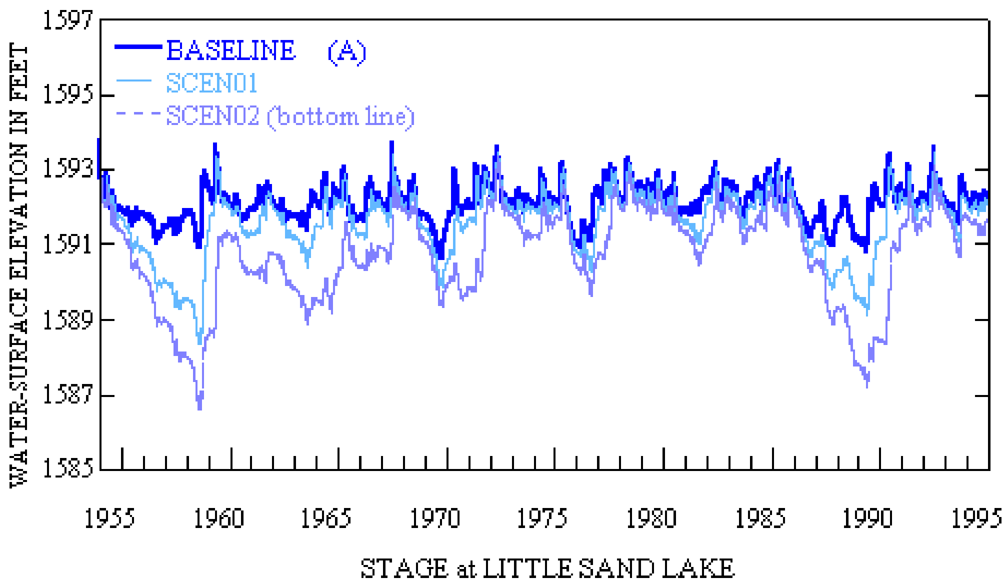
Figures 38 through 41 are residual plots of differences between baseline and each scenario for 41 years for Little Sand Lake, Duck Lake, Deep Hole Lake, and Skunk Lake, respectively. The plots are daily values and generally relate to the information presented in Table 25, but are more detailed than the values given in the table. They are plotted on the same scale for each lake.

Table 23. Pickerel Creek watershed RCHRES, Segment, and Pervious Land Segment (PLS) delineation in the Hydrological Simulation Program - Fortran

Segment corresponds to ----->>>>>perlnd	**perlnd**
250 (Upper Pickerel Creek)	525 625
260 (Rolling Stone Lake)	526 626
270 (Lower Creek 12-9)	127 527 627
280 (Upper Creek 12-9)	528
290 (Little Sand Lake)	129 529 629
300 (Bur Oak Swamp)	130 530
310 (Duck Lake)	131 531
320 (Deep Hole)	132 532
330 (Skunk Lake)	133 233

Table 24. Pickerel Creek watershed maximum, minimum, and mean Lake water-surface elevations in feet for 41 years under baseline conditions at 600 gpm (Scenario 1) and 1440 gpm (Scenario 2) pumping rates

Lake	**Maximum baseline**	**Maximum Scen 1**	**Maximum Scen 2**	**Minimum baseline**	**Minimum Scen 1**	**Minimum Scen 2**	**Mean baseline**	**Mean Scen 1**	**Mean Scen 2**
Rolling Stone	1535.8	1535.7	1535.7	1534.6	NC	NC	1535.1	NC	NC
Little Sand	1593.8	NC	NC	1590.6	1588.4	1586.6	1592.1	1591.6	1590.8
Duck Lake	1613.2	1612.7	1612.3	1610.2	1608	1606.7	1611.7	1610.9	1610.2
Deep Hole	1607	1606.9	1606.8	1604.2	1603.3	1599.7	1605.7	1605.4	1604.7
Skunk Lake	1599.4	1599.3	1599.1	1595.8	1594.6	1594.3	1597.6	1596.8	1596.4



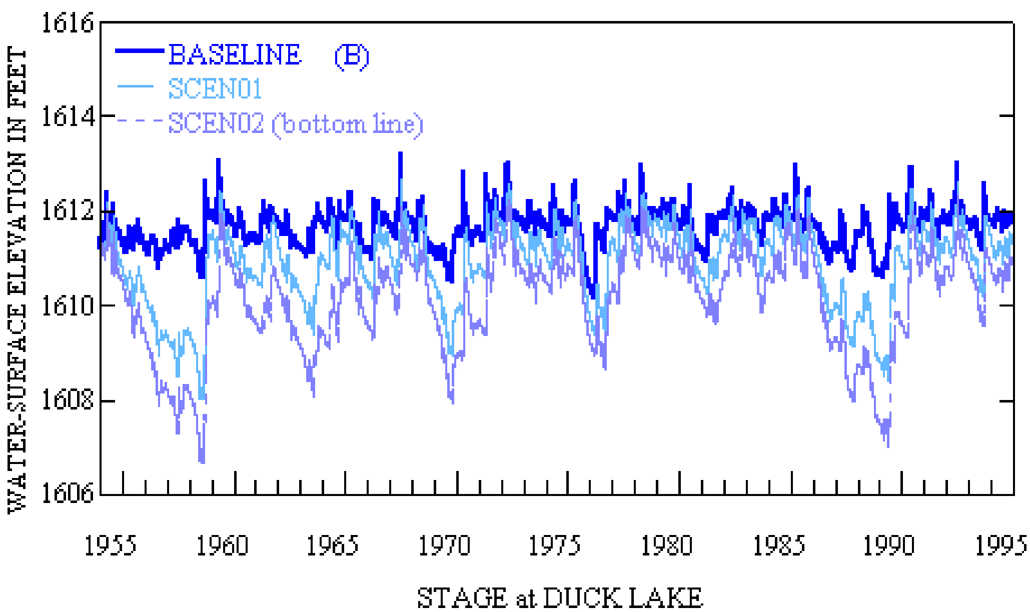


Figure 37. Daily water-surface elevations with the Hydrological Simulation Program - Fortran for (A) Little Sand Lake, (B) Duck Lake for natural/baseline condition (Pickerel) and two mine pumping scenarios (600 gpm and 1440 gpm, respectively). Note: The figures show simulated values corresponding to meteorological input for the years shown, not actual water-surface elevations for these years (con't next page).

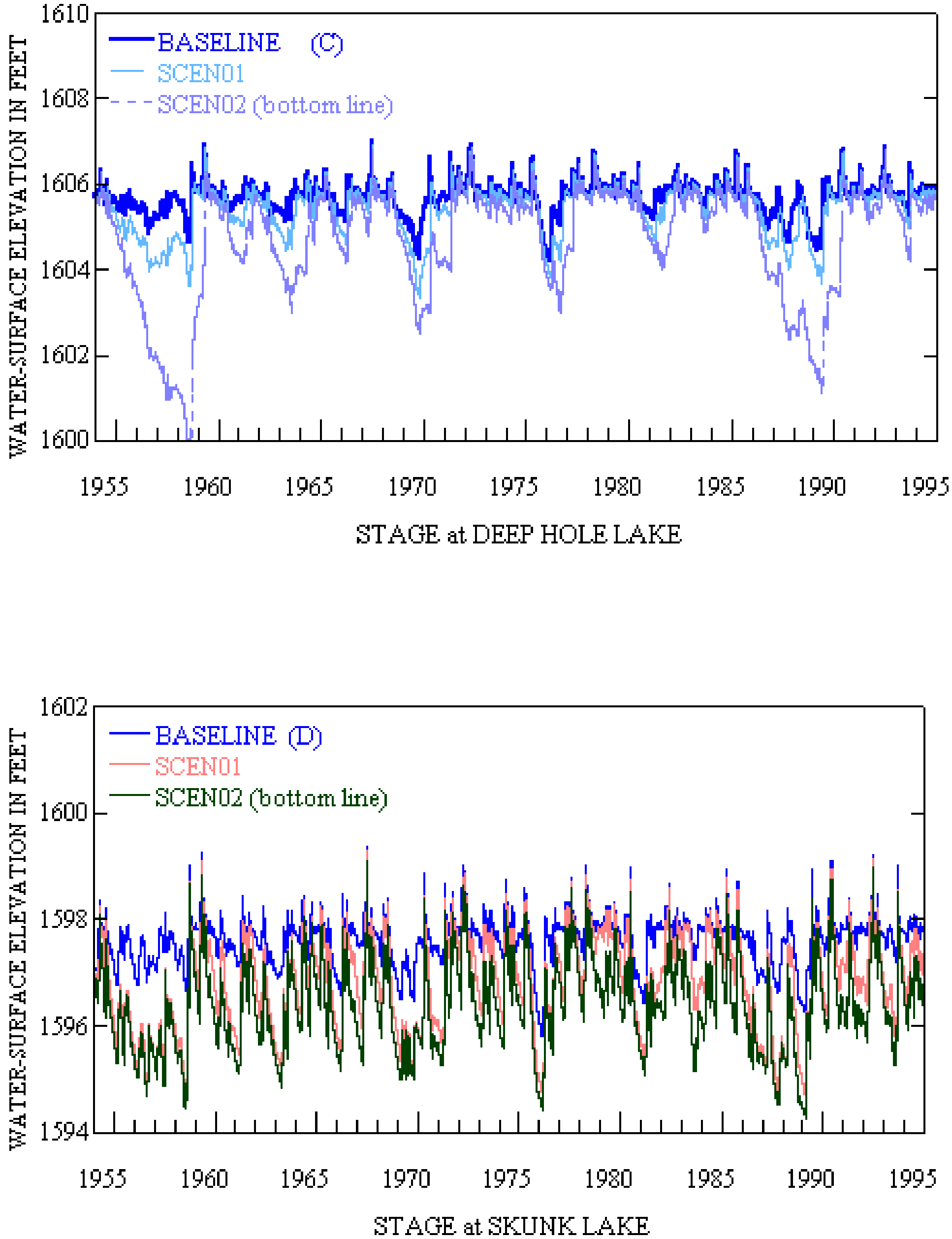


Figure 37. Daily water-surface elevations with the Hydrological Simulation Program - Fortran for (C) Deep Hole Lake, and (D) Skunk Lake for natural/baseline condition (Pickerel) and two mine pumping scenarios (600 gpm and 1440 gpm, respectively). Note: The figures show simulated values corresponding to meteorological input for the years shown, not actual water-surface elevations for these years.

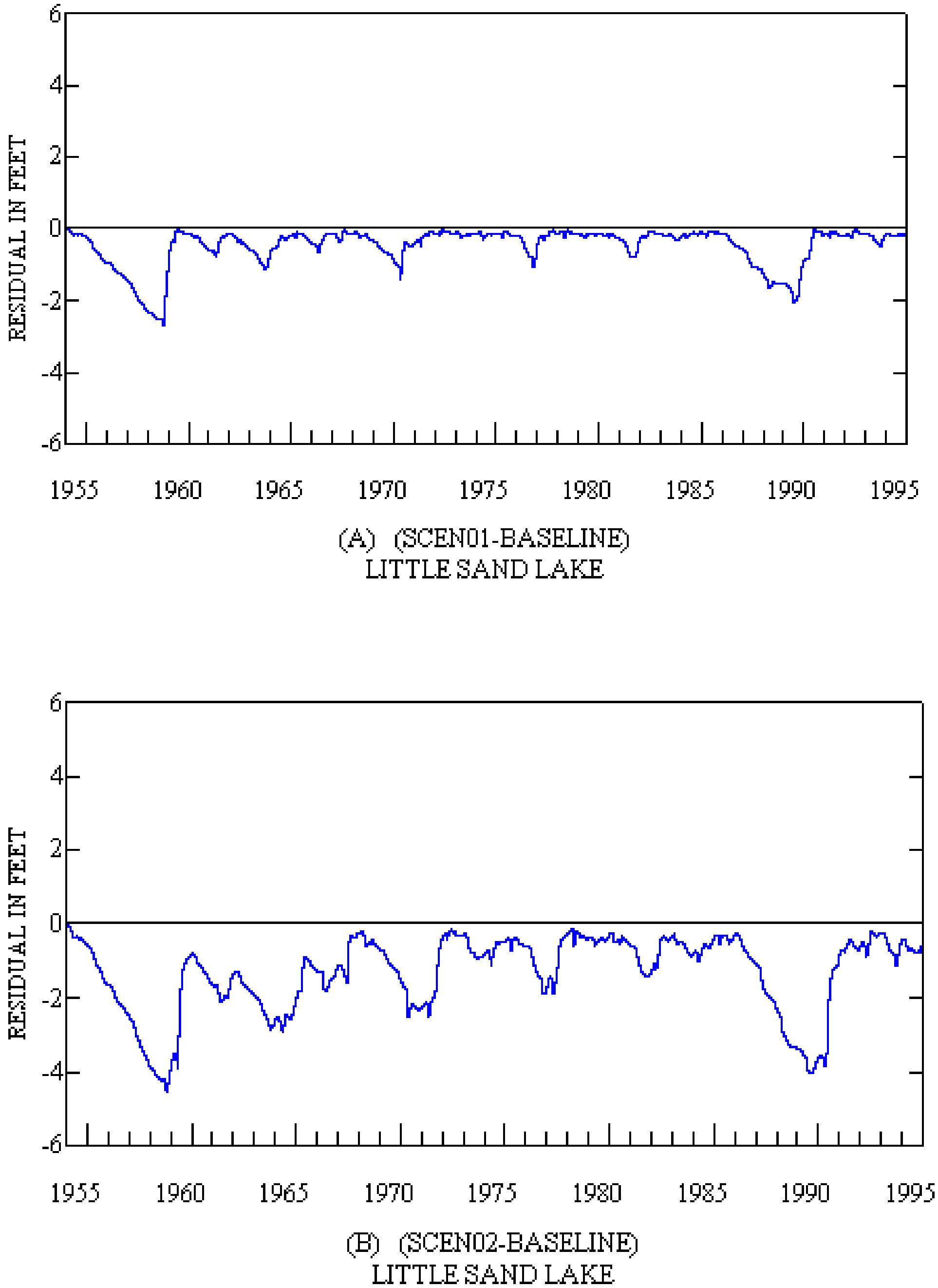
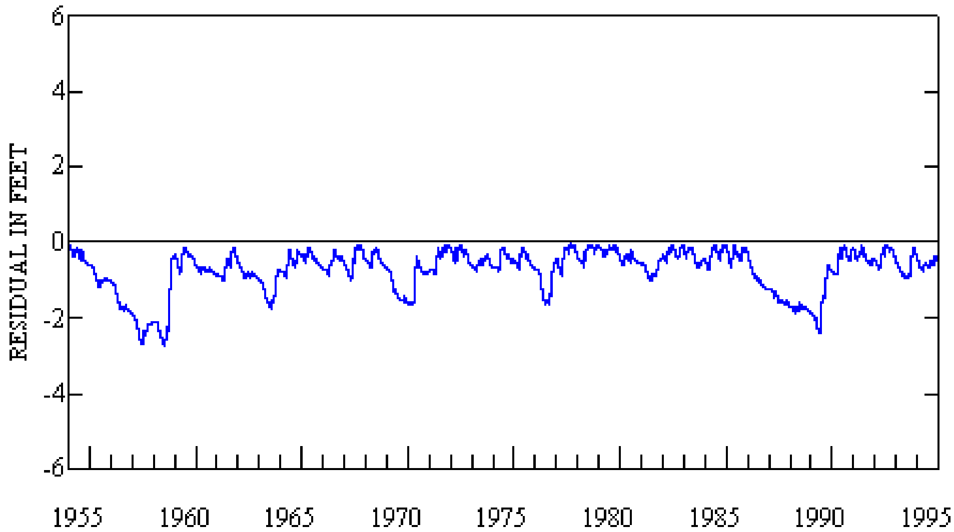
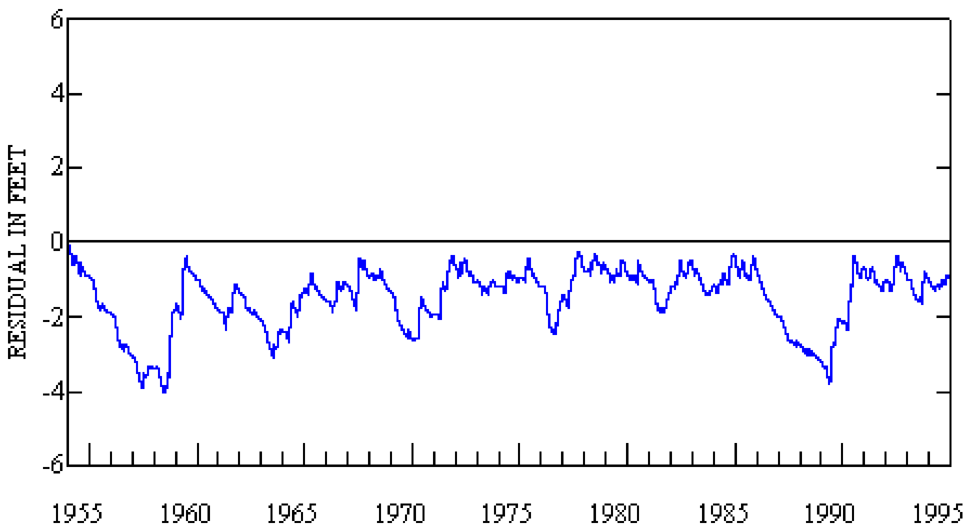


Figure 38. Difference (Residual) in water-surface elevations in feet simulated with the Hydrological Simulation Program - Fortran for Little Sand Lake between baseline conditions and (A) Scenario 1, and (B) Scenario 2. Note: The figures show simulated values corresponding to meteorological input for the years shown, not actual water-surface elevations for these years.

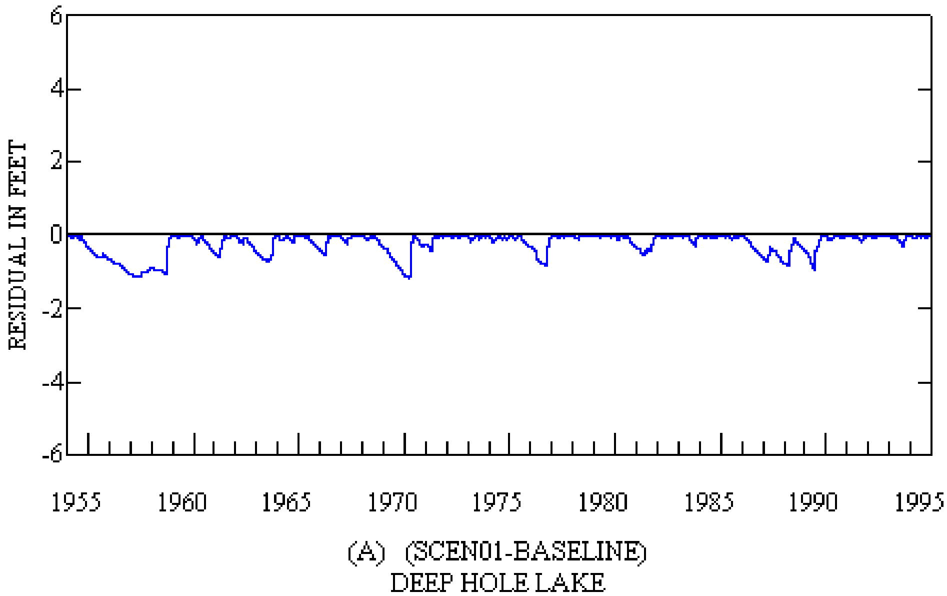


(A) (SCEN01-BASELINE)
DUCK LAKE



(B) (SCEN02-BASELINE)
DUCK LAKE

Figure 39. Difference (Residual) in water-surface elevations in feet simulated with the Hydrological Simulation Program - Fortran for Duck Lake between baseline conditions and (A) Scenario 1, and (B) Scenario 2. Note: The figures show simulated values corresponding to meteorological input for the years shown, not actual water-surface elevations for these years.



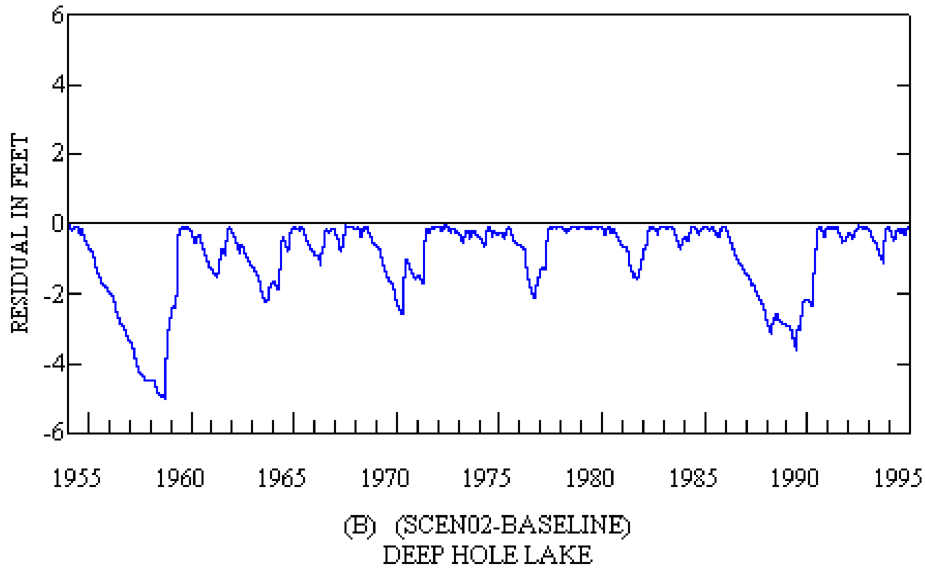
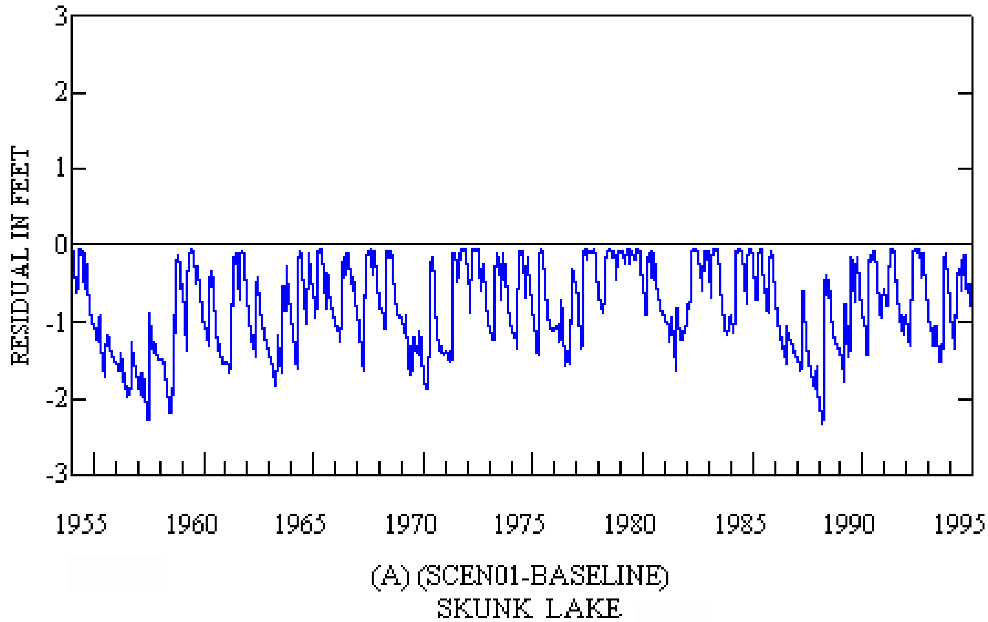


Figure 40. Difference (Residual) in water-surface elevations in feet simulated with the Hydrological Simulation Program - Fortran for Deep Hole Lake between baseline conditions and (A) Scenario 1, and (B) Scenario 2. Note: The figures show simulated values corresponding to meteorological input for the years shown, not actual water-surface elevations for these years.



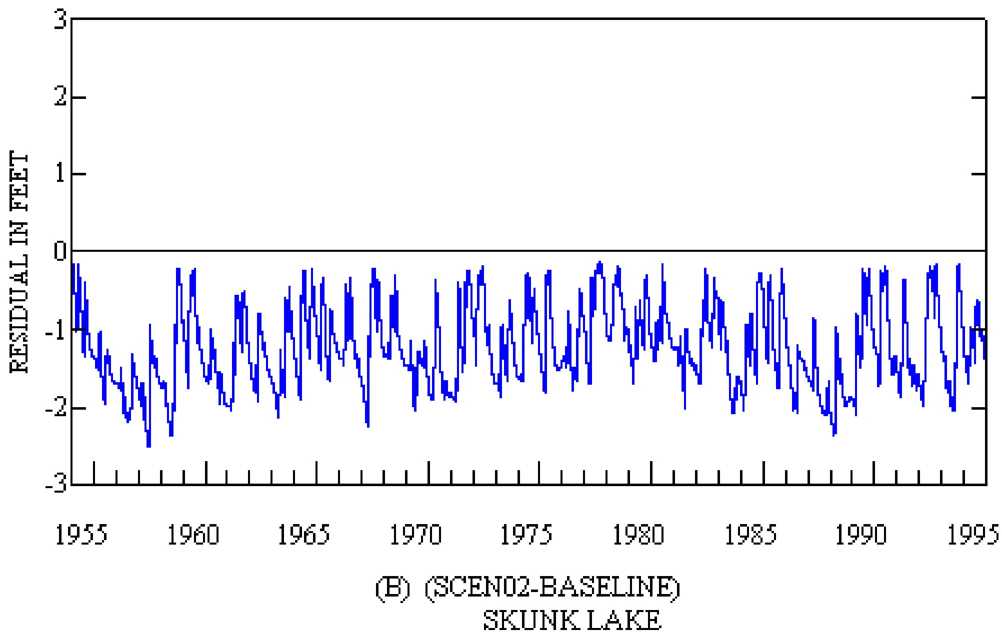


Figure 41. Difference (Residual) in water-surface elevations in feet simulated with the Hydrological Simulation Program - Fortran for Skunk Lake between baseline conditions and (A) Scenario 1, and (B) Scenario 2. Note: The figures show simulated values corresponding to meteorological input for the years shown, not actual water-surface elevations for these years.

Stream and Lake Outlet Flows
(Pick_out.wdm, Streams or Lakes location, FLOW)

Table 25 lists the values of daily streamflows in cubic feet per second and the changes between baseline and scenarios for Pickerel Creek, Little Sand Lake Inlet, and Creek 12-9 (between Rolling Stone Lake and Little Sand Lake). Table 25a shows results for the entire time simulation, and Tables 25b and 25c show results for 1956 - 1960 and 1987 - 1990, respectively. These years were chosen to focus on changes in the flow in drought periods for consideration of stress conditions during shorter time intervals.

The minimum values are zero or close to zero in the baseline and all scenarios, but changes occur in maximum and mean values. The values for Pickerel Creek did not change in any of the time periods; therefore, it was omitted from Tables 25b and 25c. Variation statistics for these locations also are presented in Appendix 4 for bioassessment.

Table 26 lists the lake outflow from the outlets of the five lakes. Minimum flows from the lakes are all zero in the baseline and both scenarios. The maximum values in Duck and Deep Hole Lakes show the greatest change and are shown in gray in Table 26a representing the 41-year evaluation. Tables 26b and 26c contain the lake outflows for 1956 - 1960 and 1987 - 1991 input meteorological conditions, respectively; Rolling Stone, Little Sand, Duck, and Deep Hole Lakes experience a change in maximum outflow. There are also very slight decreases in mean values in Skunk Lake listed as NC in Tables 26b and 26c (due to significant figures not reflecting negligible change).

Figure 42 shows flow duration curves for Creek 12-9 for (A) the entire simulation time period, (B) 1956-1960, and (C) 1987-1991. Figure 43 shows the same for Little Sand Lake Inlet. The plots show the impact of both scenarios at both pumping rates.

Figures 44 - 47 show flow duration curves for Little Sand, Duck, Deep Hole, and Skunk Lakes, respectively, for (A) the entire simulation time period, (B) 1956 -1960, and (C) 1987-1991. The plots show there is an effect at both pumping rates. Figures 48 - 51 are plots of differences in flow (residuals) between baseline and Scenarios 1 and 2 for the entire simulation period.

Table 25a. Maximum, minimum, and mean streamflow in cfs for the Pickerel Creek watershed simulated with the Hydrological Simulation Program - Fortran for the baseline conditions and Scenarios 1 and 2 for the full 41-year trial period.

Streams	Maximum baseline (cfs)	Maximum Scen 1 (cfs)	Maximum Scen 2 (cfs)	Minimum baseline (cfs)	Minimum Scenarios 1&2 (cfs)	Mean baseline (cfs)	Mean Scen 1 (cfs)	Mean Scen 2 (cfs)
PICKEREL CREEK	37.6	NC	NC	0	NC	1.7	NC	NC
CREEK 12-9	71.4	66.7	58.4	0	NC	2.8	2.2	1.6
Little Sand Inlet	22.7	16.1	10	0	NC	0.8	0.5	0.2

Table 25b. Maximum, minimum, and mean streamflow in cfs for the Pickerel Creek watershed simulated with the Hydrological Simulation Program - Fortran for the baseline conditions and Scenarios 1 and 2 for meteorological conditions corresponding to the drought period of 1956 - 1960. Pickerel Creek values did not change.

Streams	Maximum baseline (cfs)	Maximum Scen 1 (cfs)	Maximum Scen 2 (cfs)	Minimum baseline (cfs)	Minimum Scenarios 1&2 (cfs)	Mean baseline (cfs)	Mean Scen 1 (cfs)	Mean Scen 2 (cfs)
CREEK 12-9	41.8	37.6	33.9	0.2	0.1	1.9	1.4	1
Little Sand Inlet	16.8	12	3.2	0	0	0.5	0.3	0.1

Table 25c. Maximum, minimum, and mean streamflow in cfs for the Pickerel Creek watershed simulated with the Hydrological Simulation Program - Fortran for the baseline conditions and Scenarios 1 and 2 for meteorological conditions corresponding to the drought period of 1987 - 1991. Pickerel Creek values did not change.

Streams	Maximum baseline (cfs)	Maximum Scen 1 (cfs)	Maximum Scen 2 (cfs)	Minimum baseline (cfs)	Minimum Scenarios 1&2 (cfs)	Mean baseline (cfs)	Mean Scen 1 (cfs)	Mean Scen 2 (cfs)
CREEK 12-9	39.9	36.5	34.1	0.1	0	1.9	1.4	1
Little Sand Inlet	11.2	8.2	3.2	0	0	0.5	0.3	0.1

Table 26a. Maximum, minimum, and mean lake outlet outflow in cfs for the Pickerel Creek watershed simulated with the Hydrological Simulation Program - Fortran for the baseline conditions and scenarios 1 and 2 for the full 41-year trial period.

Lake Flow	Maximum baseline (cfs)	Maximum Scen 1 (cfs)	Maximum Scen 2 (cfs)	Minimum baseline (cfs)	Minimum Scenarios1 &2 (cfs)	Mean baseline (cfs)	Mean Scen 1 (cfs)	Mean Scen 2 (cfs)
ROLLING STONE	115.1	111.5	106	0	NC	7	6.4	5.8
LITTLE SAND	19.2	NC	NC	0	NC	1.5	0.9	0.3
DUCK LAKE	5.6	1.8	1.1	0	NC	0.3	0.1	0
DEEP HOLE	18.1	14.7	9.4	0	NC	0.6	0.4	0.2
SKUNK LAKE	1.3	1.2	1.1	0	NC	0.1	0	0

Table 26b. Maximum, minimum, and mean lake outlet outflow in cfs for the Pickerel Creek watershed simulated with the Hydrological Simulation Program - Fortran for the baseline conditions and scenarios 1 and 2 for meteorological conditions corresponding to the drought period of 1956 - 1960.

Lake Flow	Maximum baseline (cfs)	Maximum Scen 1 (cfs)	Maximum Scen 2 (cfs)	Minimum baseline (cfs)	Minimum Scenarios 1&2 (cfs)	Mean baseline (cfs)	Mean Scen 1 (cfs)	Mean Scen 2 (cfs)
ROLLING STONE	98.2	93.8	89	0	NC	5	4.5	4.1
LITTLE SAND	16.8	11.8	0.1	0	NC	0.9	0.4	0
DUCK LAKE	4.3	1.3	0.4	0	NC	0.2	0	0
DEEP HOLE	12.5	10.8	2.9	0	NC	0.4	0.2	0.1
SKUNK LAKE	1.2	1.1	1	0	NC	0	NC	NC

Table 26c. Maximum, minimum, and mean lake outlet outflow in cfs for the Pickerel Creek watershed simulated with the Hydrological Simulation Program - Fortran for the baseline conditions and scenarios 1 and 2 for meteorological conditions corresponding to the drought period of 1987 - 1991.

Lake Flow	Maximum baseline (cfs)	Maximum Scen 1 (cfs)	Maximum Scen 2 (cfs)	Minimum baseline (cfs)	Minimum Scenarios 1&2 (cfs)	Mean baseline (cfs)	Mean Scen 1 (cfs)	Mean Scen 2 (cfs)
ROLLING STONE	80.4	77.1	73.4	0	NC	4.9	4.4	4
LITTLE SAND	13.1	8.8	0.6	0	NC	0.9	0.4	0
DUCK LAKE	3	1.4	0.5	0	NC	0.2	0	0
DEEP HOLE	8.1	6.8	2.6	0	NC	0.4	0.2	0.1
SKUNK LAKE	1.1	1.1	0.9	0	NC	0	NC	NC

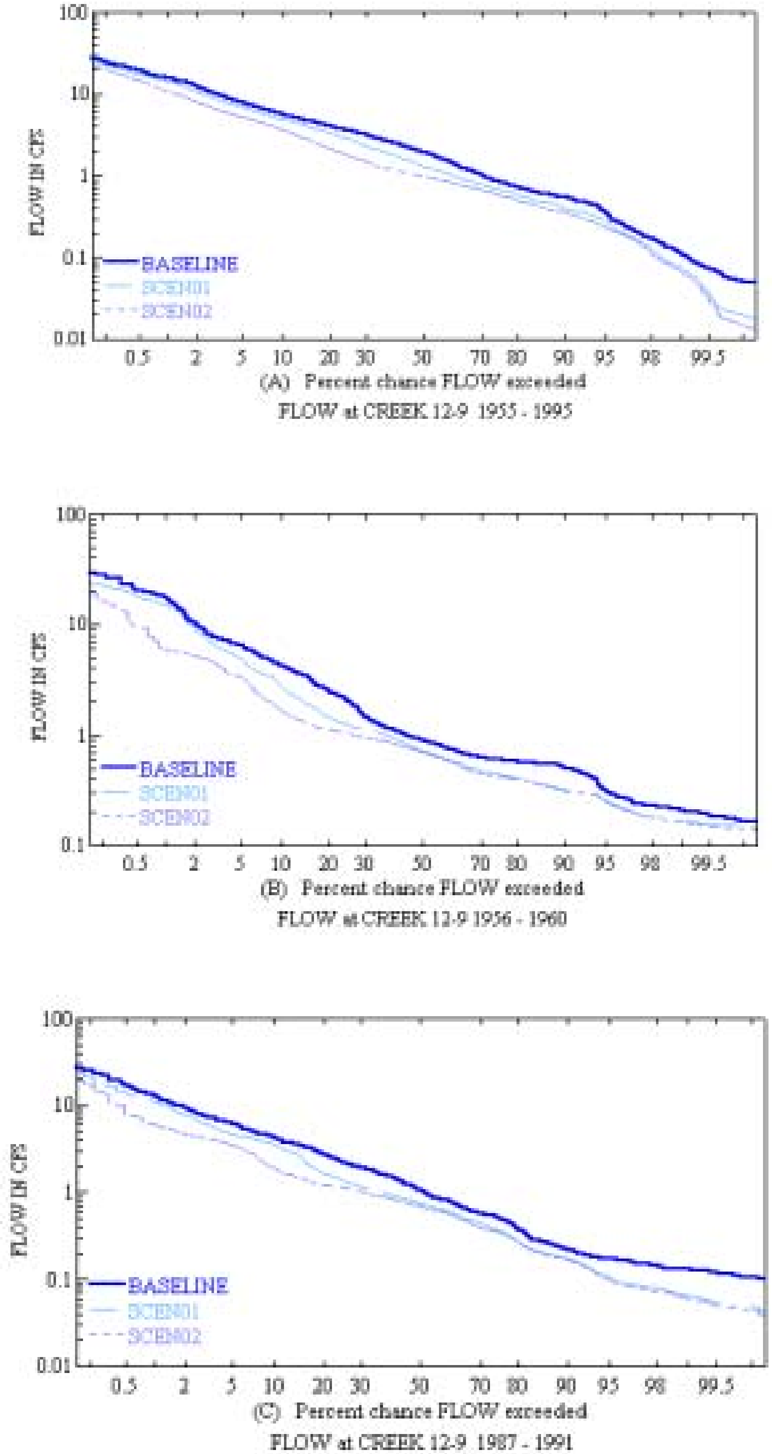


Figure 42. Flow duration curves for the daily flows simulated with the Hydrological Simulation Program - Fortran for baseline conditions and Scenarios 1 and 2 at Creek 12-9 for meteorological conditions corresponding to (A) 1955 - 1995, (B) 1956 - 1960, and (C) 1987 - 1991.

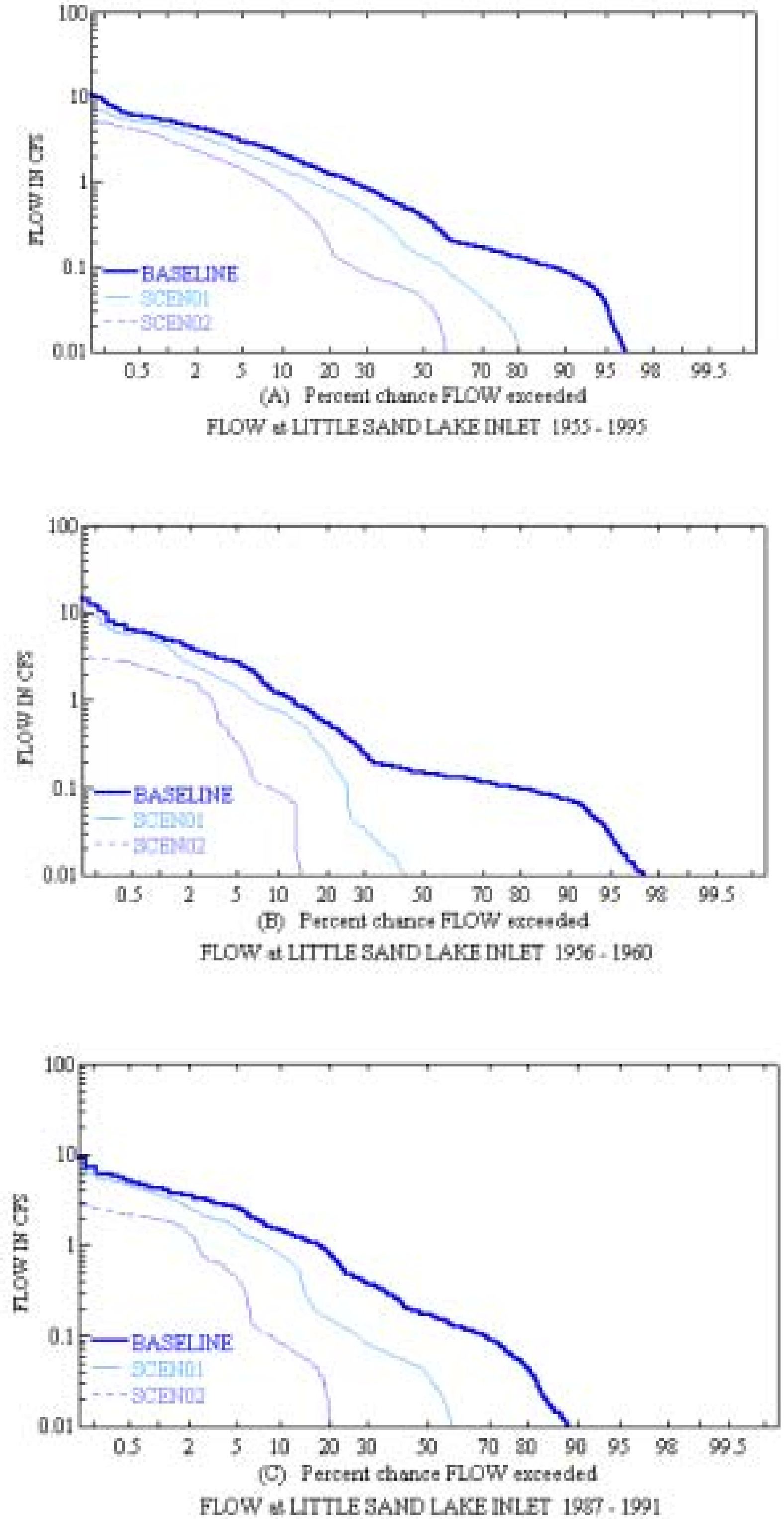


Figure 43. Flow-duration curves for the daily flows simulated with the Hydrological Simulation Program - Fortran for baseline conditions and Scenarios 1 and 2 at Little Sand Lake Inlet for meteorological conditions corresponding to (A) 1955 - 1995, (B) 1956 - 1960, and (C) 1987 - 1991.

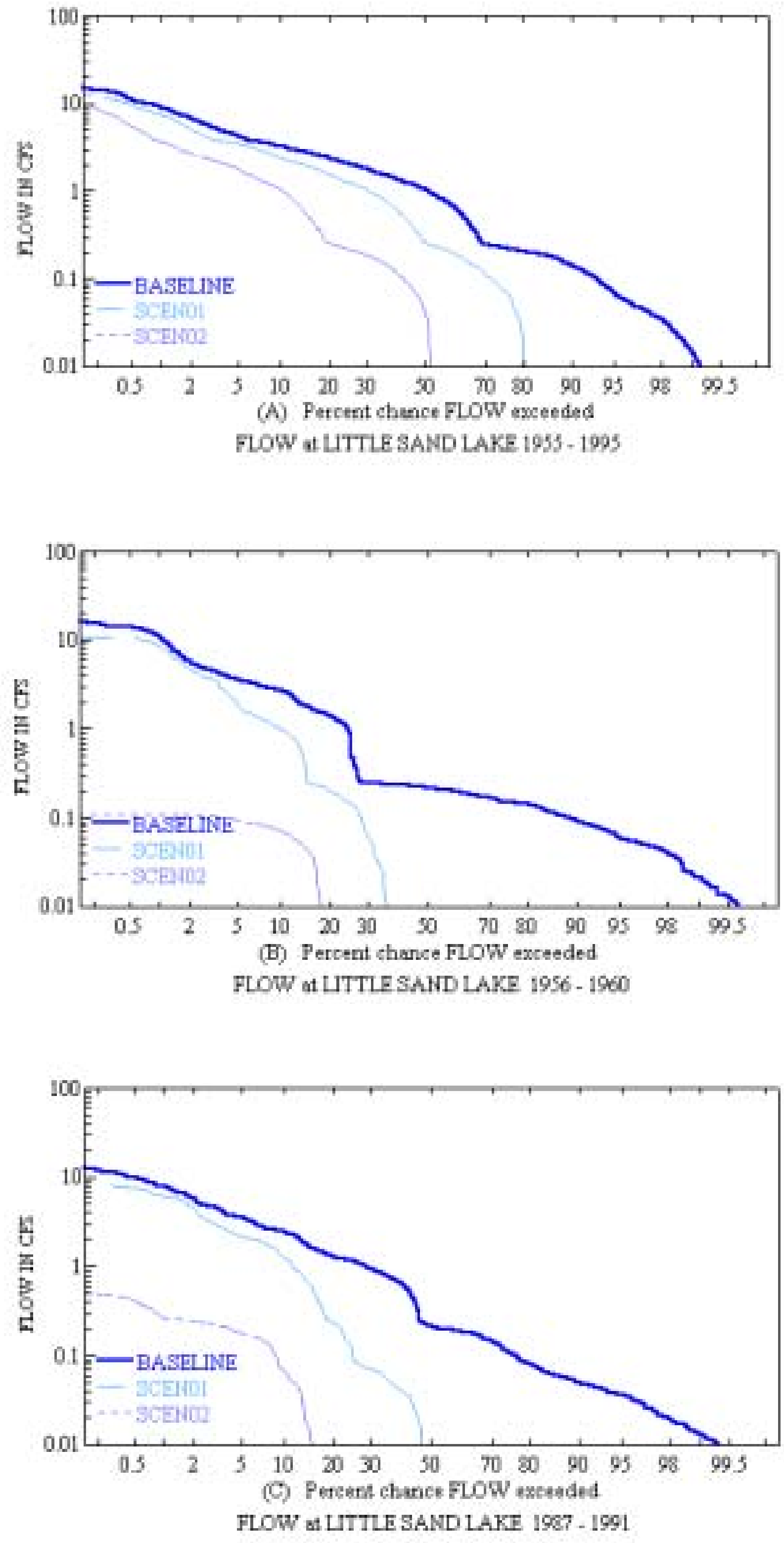


Figure 44. Flow-duration curves for the daily flows simulated with the Hydrological Simulation Program - Fortran for baseline conditions and Scenarios 1 and 2 at Little Sand Lake for meteorological conditions corresponding to (A) 1955 - 1995, (B) 1956 - 1960, and (C) 1987 - 1991.

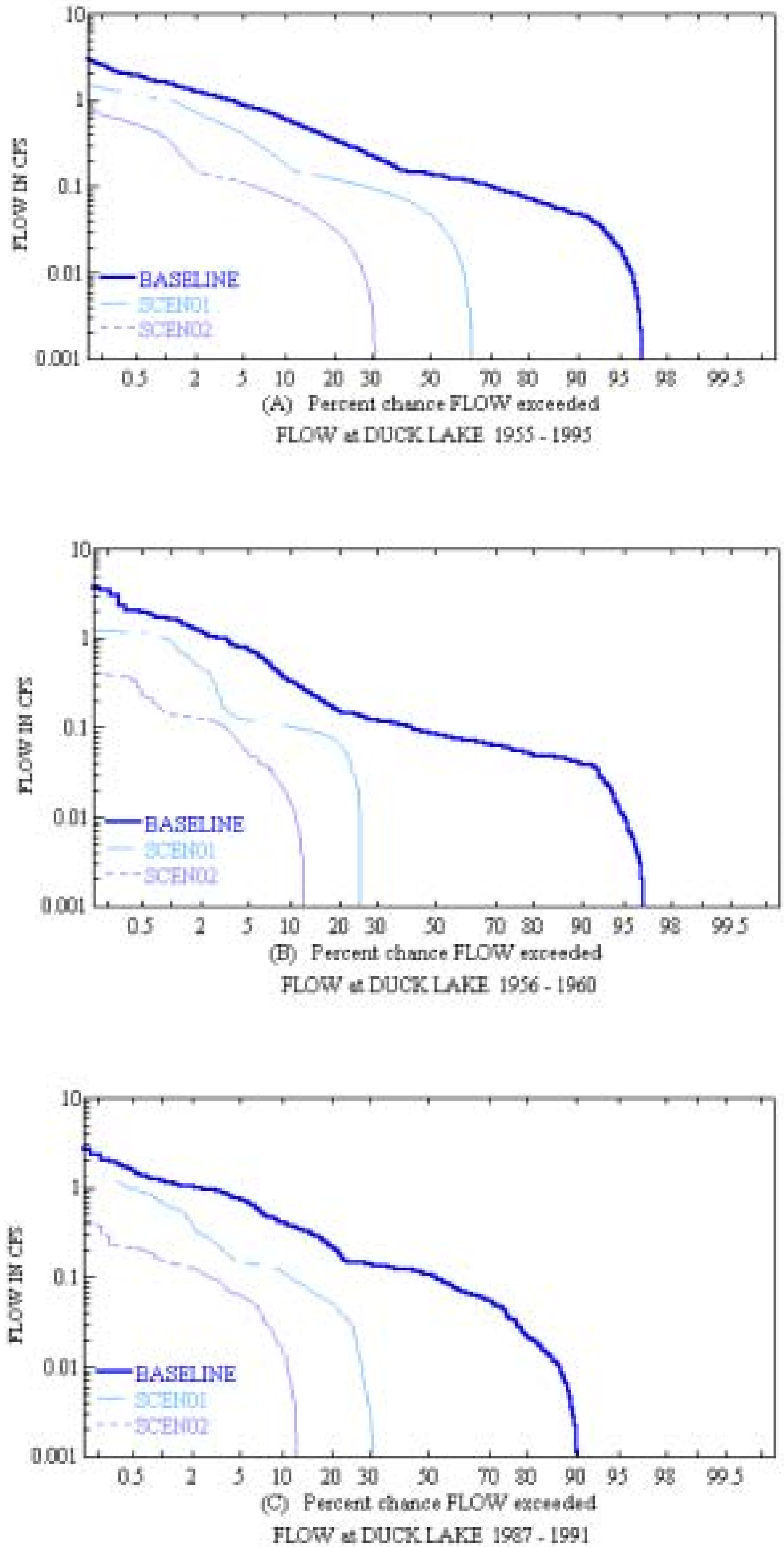


Figure 45. Flow-duration curves for the daily flows simulated with the Hydrological Simulation Program - Fortran for baseline conditions and Scenarios 1 and 2 at Duck Lake for meteorological conditions corresponding to (A) 1955 - 1995, (B) 1956 - 1960, and (C) 1987 - 1991.

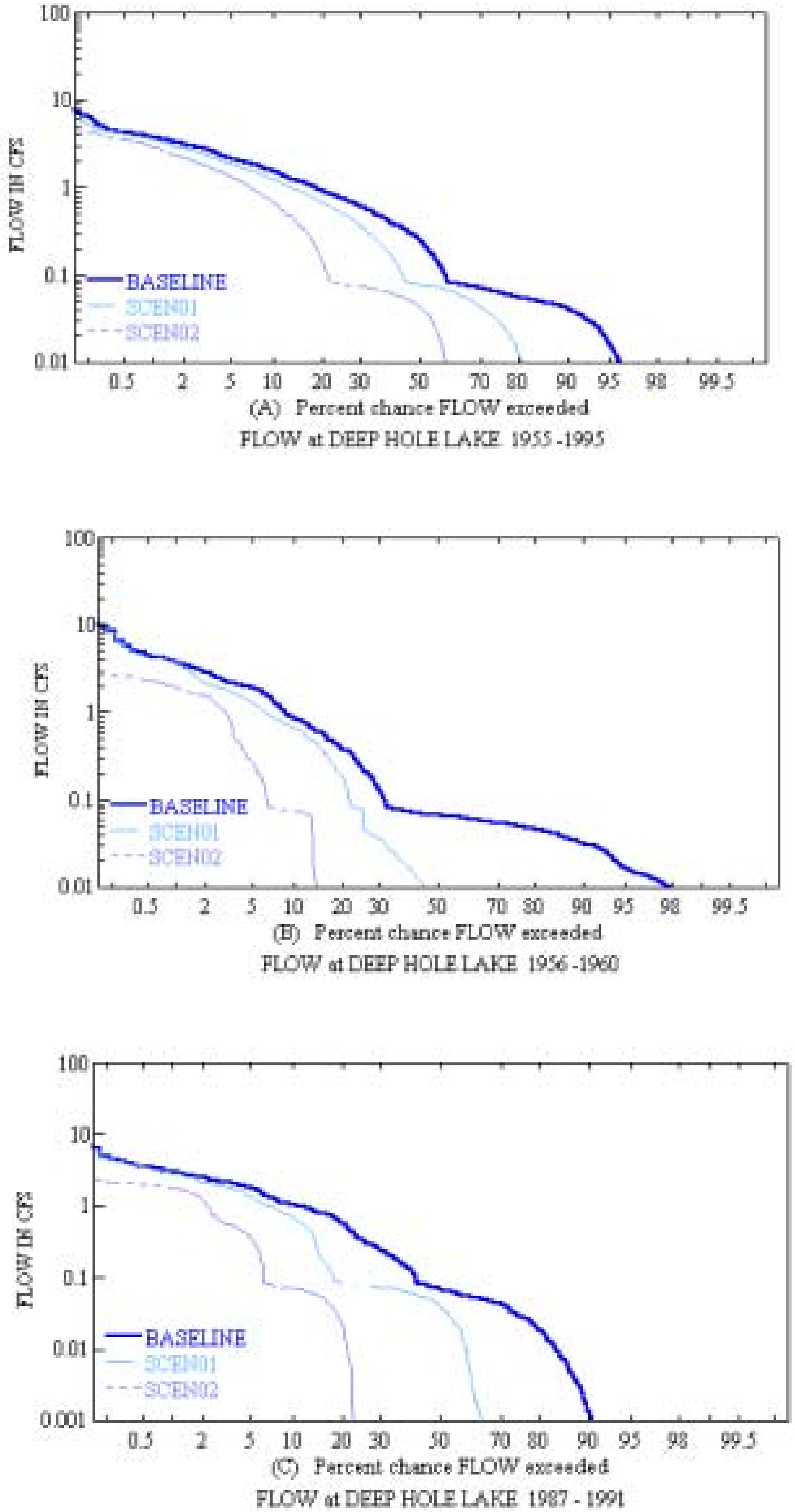


Figure 46. Flow duration curves for the daily flows simulated with the Hydrological Simulation Program - Fortran for baseline conditions and Scenarios 1 and 2 at Deep Hole Lake for meteorological conditions corresponding to (A) 1955 - 1995, (B) 1956 - 1960, and (C) 1987 - 1991.

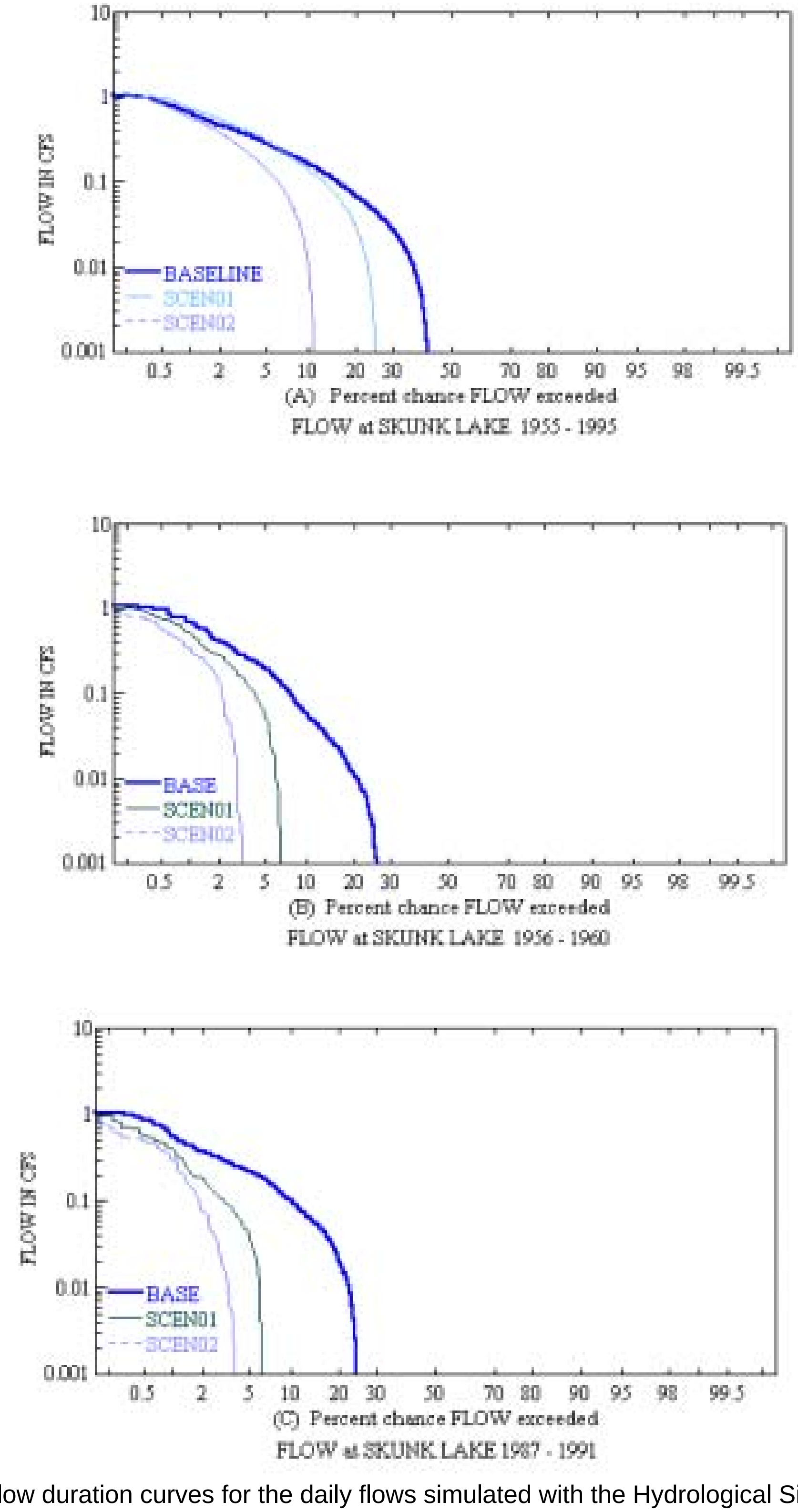
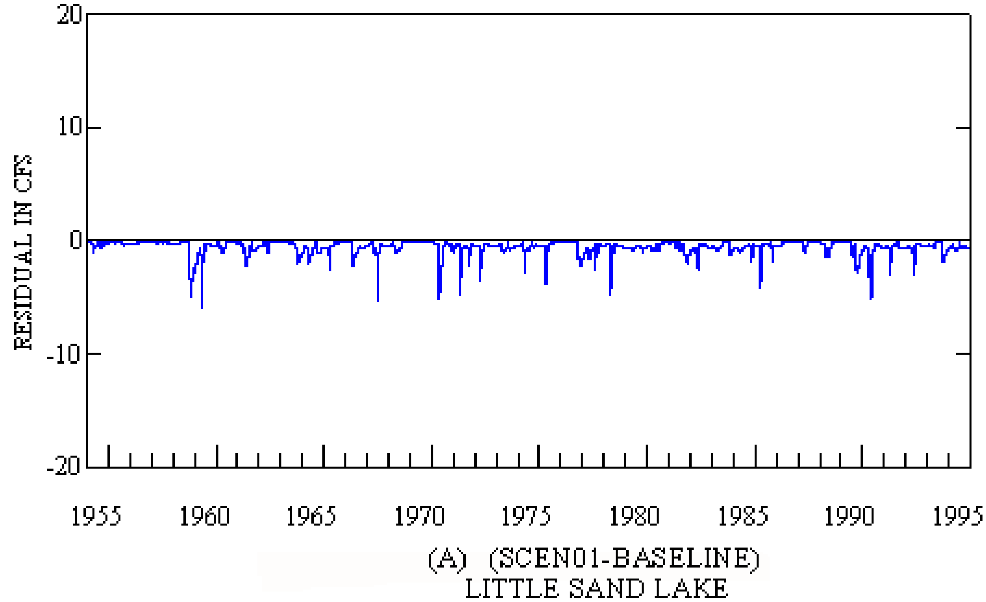


Figure 47. Flow duration curves for the daily flows simulated with the Hydrological Simulation Program - Fortran for baseline conditions and Scenarios 1 and 2 at Skunk Lake for meteorological conditions corresponding to (A) 1955 - 1995, (B) 1956 - 1960, and (C) 1987 - 1991.



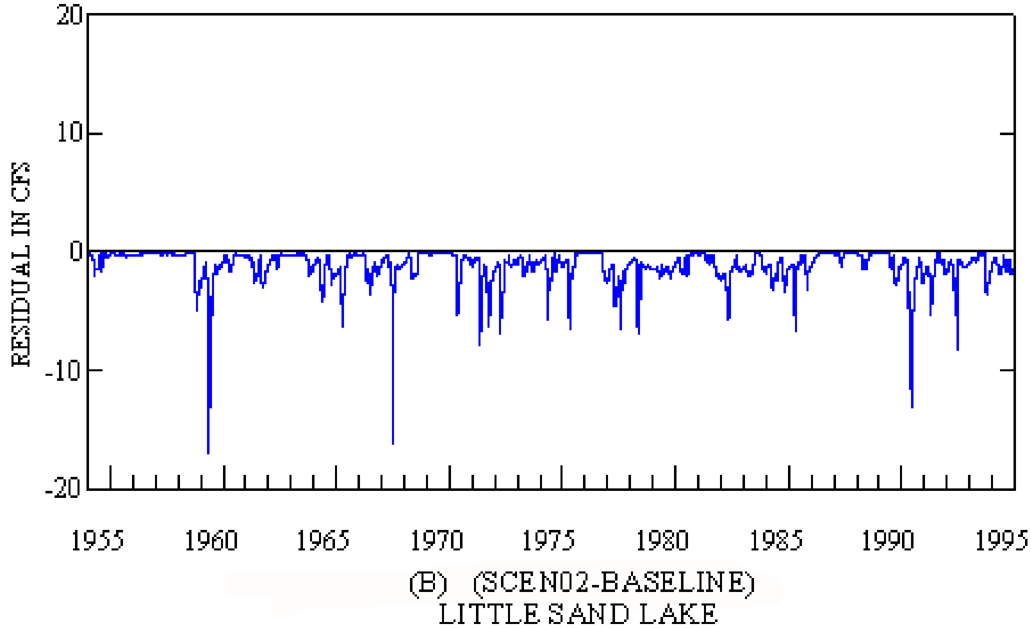
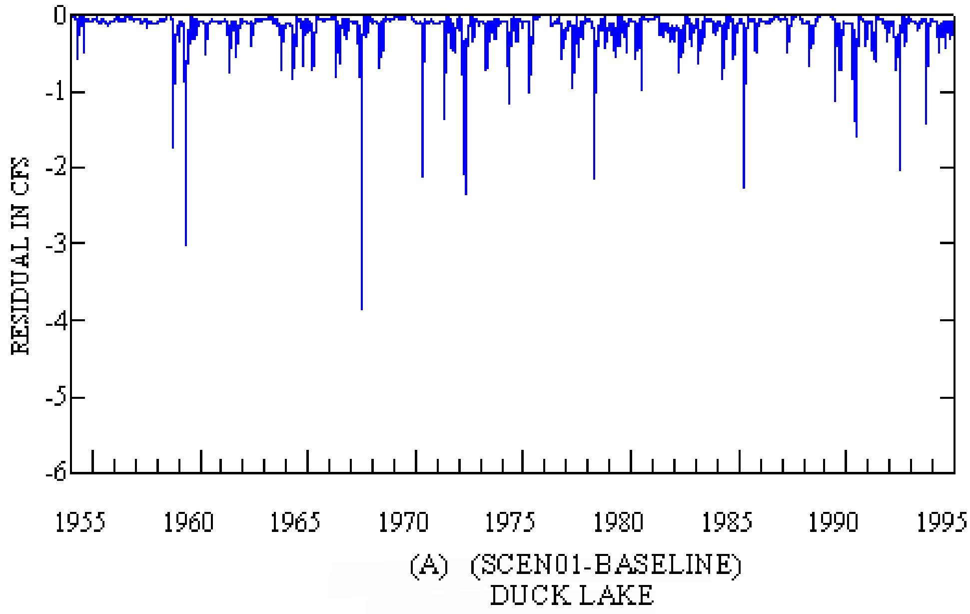


Figure 48. Difference (Residual) in outlet flows simulated with the Hydrological Simulation Program - Fortran for Little Sand Lake between baseline conditions and (A) Scenario 1, and (B) Scenario 2.



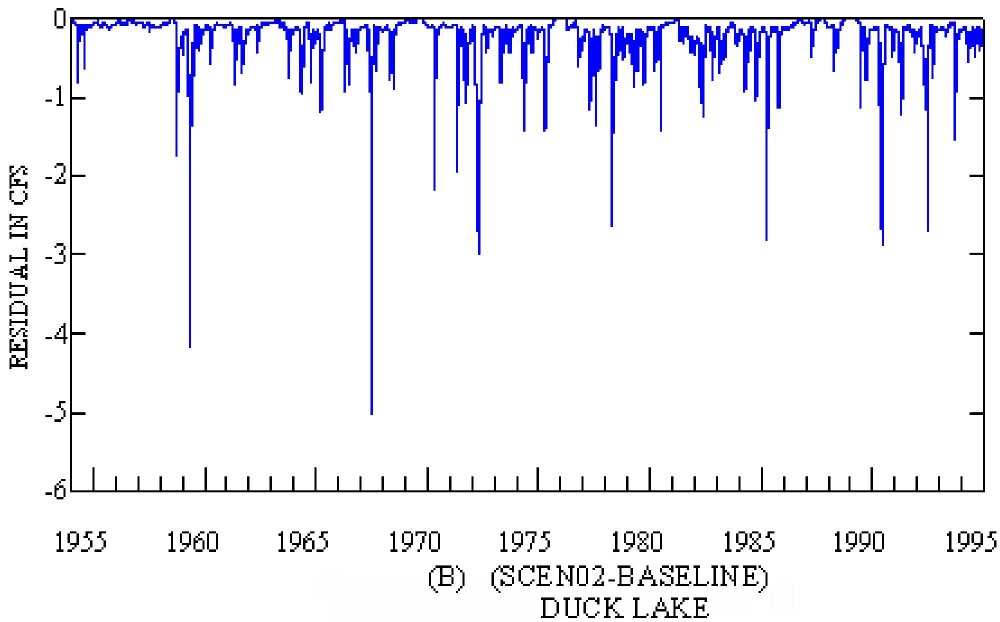
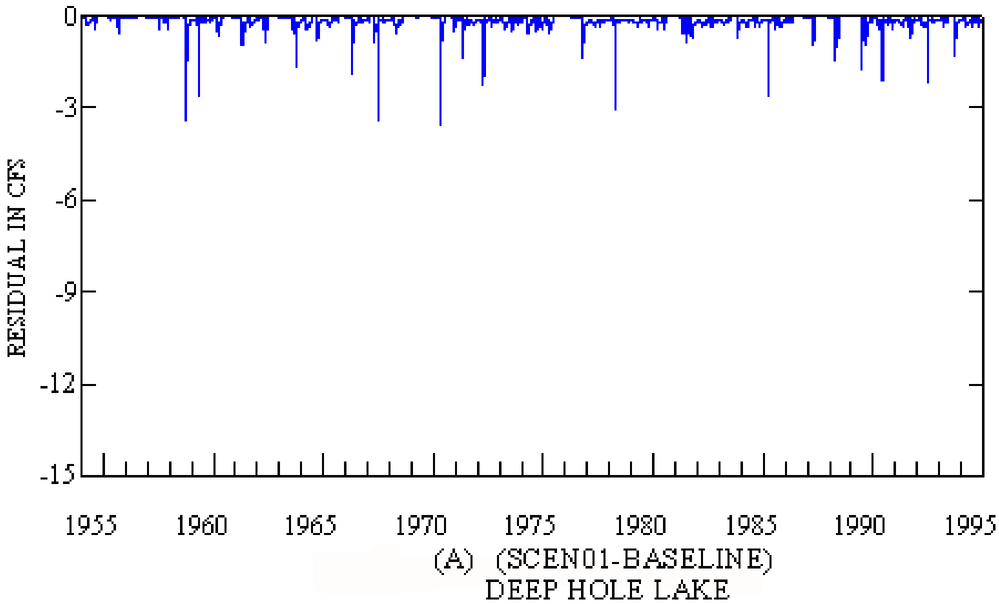


Figure 49. Difference (Residual) in outlet flows simulated with the Hydrological Simulation Program - Fortran for Duck Lake between baseline conditions and (A) Scenario 1, and (B) Scenario 2.



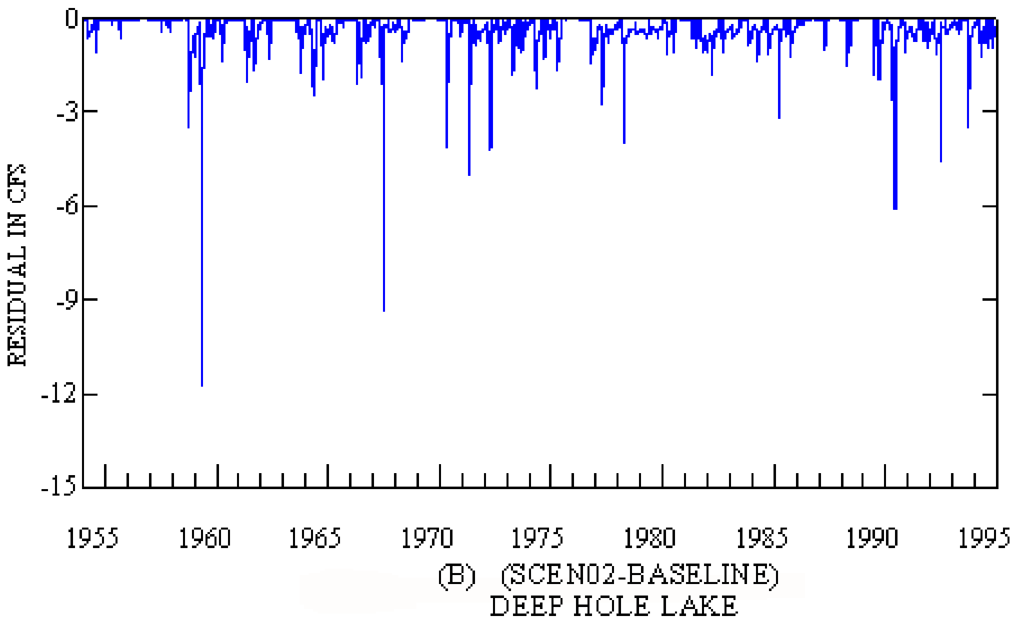
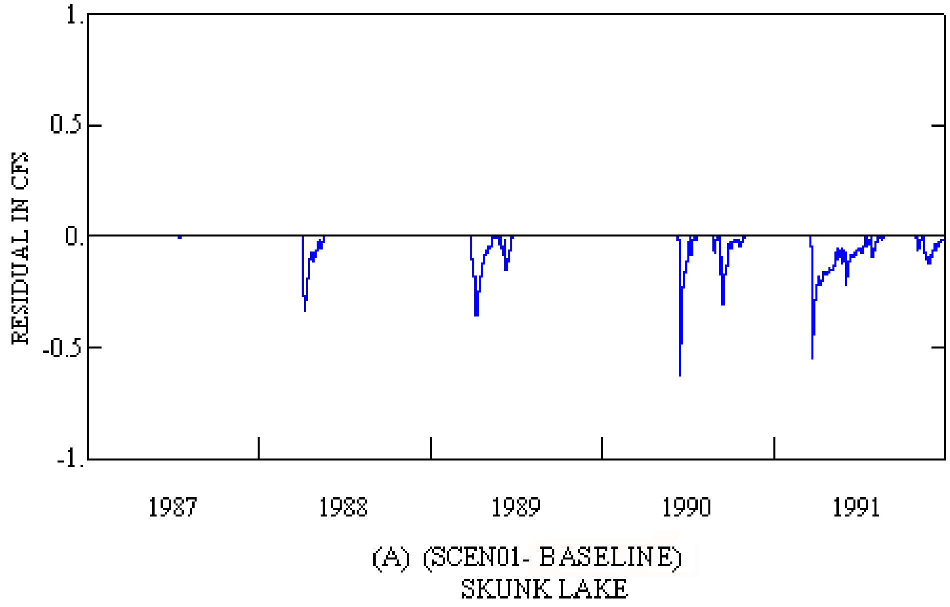


Figure 50. Difference (Residual) in outlet flows simulated with the Hydrological Simulation Program - Fortran for Deep Hole Lake between baseline conditions and (A) Scenario 1, and (B) Scenario 2.



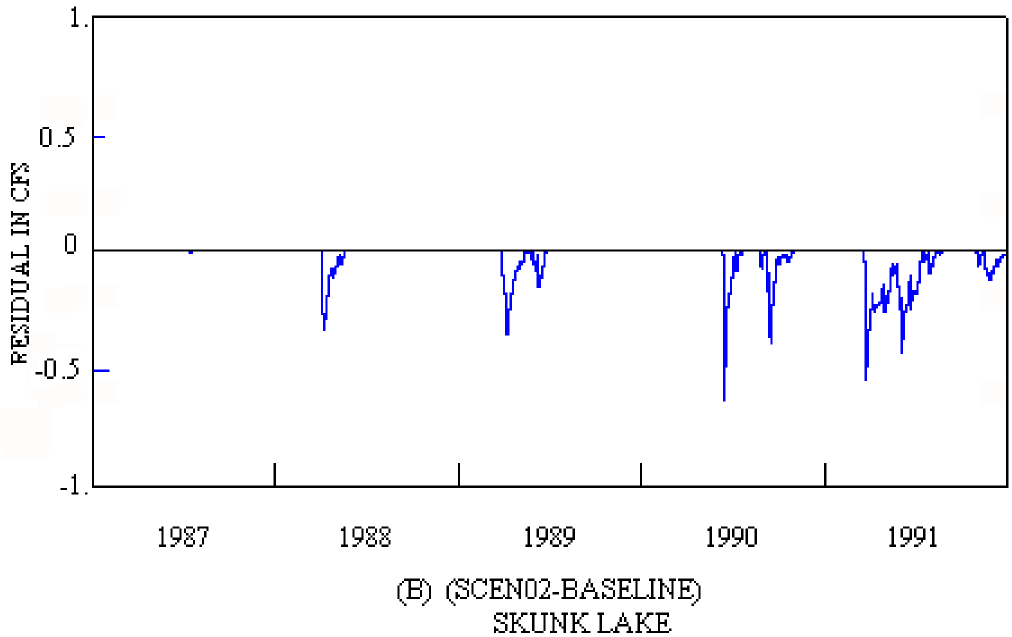


Figure 51. Difference (Residual) in outlet flows simulated with the Hydrological Simulation Program - Fortran for Skunk Lake between baseline conditions and (A) Scenario 1, and (B) Scenario 2.

Wetlands
(Pick_out.wdm, PERLNDS, GWEL)

Groundwater elevation results are calculated in those of the pervious land segments which represent wetlands and where groundwater elevation data from wells are available. Most segments experience no change (Table 27). Wetlands in segments 290, 300, 301, 320, and 330 experience changes and are in the segments closest to the mine where Little Sand Lake, Bur Oak Swamp, Duck Lake, Deep Hole Lake, and Skunk Lake, respectively, are located. Figures 52 - 56 show the residual plots of differences between baseline and (A) Scenario 1, and (B) Scenario 2 for the full 41-year simulation for these wetlands.

Table 27. Pickerel Creek watershed 1955-1995 groundwater elevations in wetland PERLNDS for baseline conditions and Scenarios 1 (600 gpm) and 2 (1440 gpm)

Pervious Land Segment	**Max. baseline (cfs)**	**Max. Scen 1 (cfs)**	**Max. Scen 2 (cfs)**	**Minimum baseline (cfs)**	**Minimum Scen 1 (cfs)**	**Minimum Scen 2 (cfs)**	**Mean baseline (cfs)**	**Mean Scen 1 (cfs)**	**Mean Scen 2 (cfs)**
PER 525 Upper Pickerel Ck. Recharge Wetl	1596.6	NC	NC	1594.1	NC	NC	1595.2	NC	NC
PER 526 Rolling Stone Lake Weir Recharge Wetl	1644.7	NC	NC	1642.1	NC	NC	1643.3	NC	NC
PER 527 L.Creek 12-9 Recharge Wetland	1629.5	NC	NC	1627	NC	NC	1627.9	NC	NC
PER 528 Recharge Wetl	1603.1	NC	NC	1600.9	NC	NC	1601.6	NC	NC
PER529 Little Sand Lake	1602.3	NC	1602	1600	1599.6	1597.9	1600.8	1600.4	1599.8
PER530 Bur Oak Swamp	1645.4	1645.3	1645.2	1643	1642.6	1641.7	1643.9	1643.6	1643.2
PER531 Duck Lake	1621.6	1621.3	1619.7	1619.1	1617.9	1612.5	1620.1	1619.3	1615.2
PER532 Deep Hole Lake	1647.6	1647.5	1647.5	1645.1	1644.9	1644.5	1646.1	1645.9	1645.5
PER 533 Skunk Lake	1608.6	NC	1608.3	1606.1	1605.2	1600.9	1607.2	1606.6	1604.7
PER625 Upper Pickerel Creek Discharge Wetl	1550.1	NC	NC	1547.9	NC	NC	1548.6	NC	NC
PER626 Rolling Stone Lake Weir Discharge Wetl	1547.2	NC	NC	1544.9	NC	NC	1545.6	NC	NC
PER627 L. Creek 12-9 Discharge Wetl.	1553.4	NC	NC	1551.7	NC	NC	1552.6	NC	NC

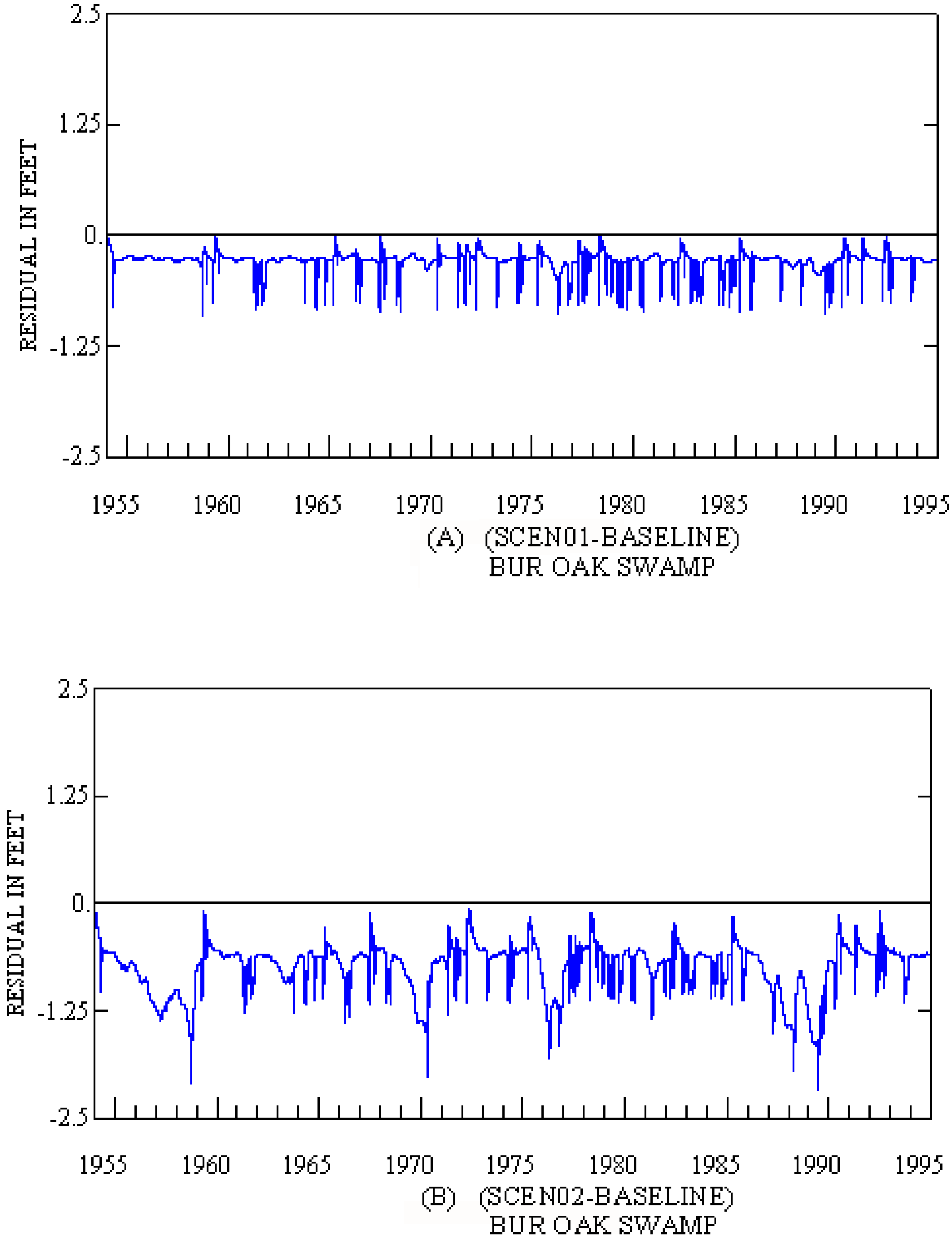
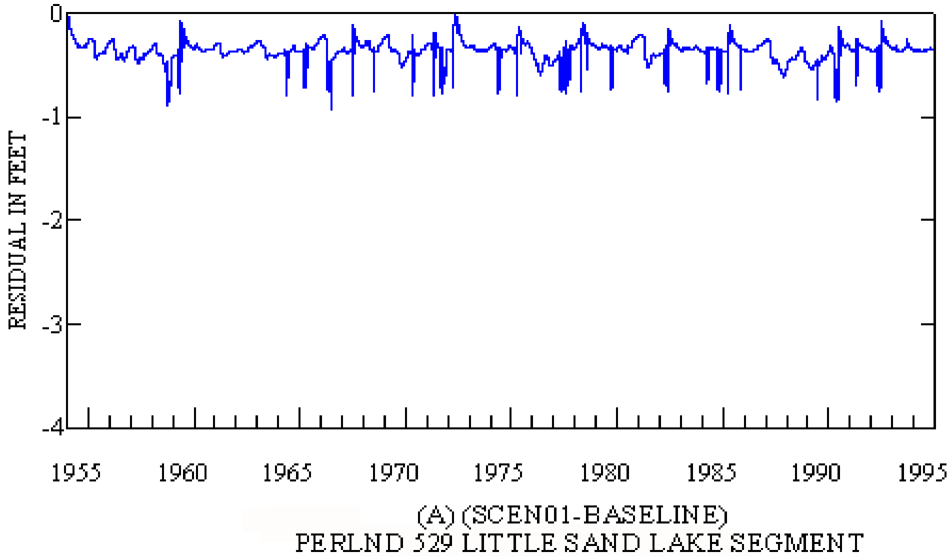


Figure 52. Difference (Residual) in wetland water levels simulated with the Hydrological Simulation Program - Fortran for PERLND 530 (Bur Oak Swamp) between baseline conditions and (A) Scenario 1, and (B) Scenario



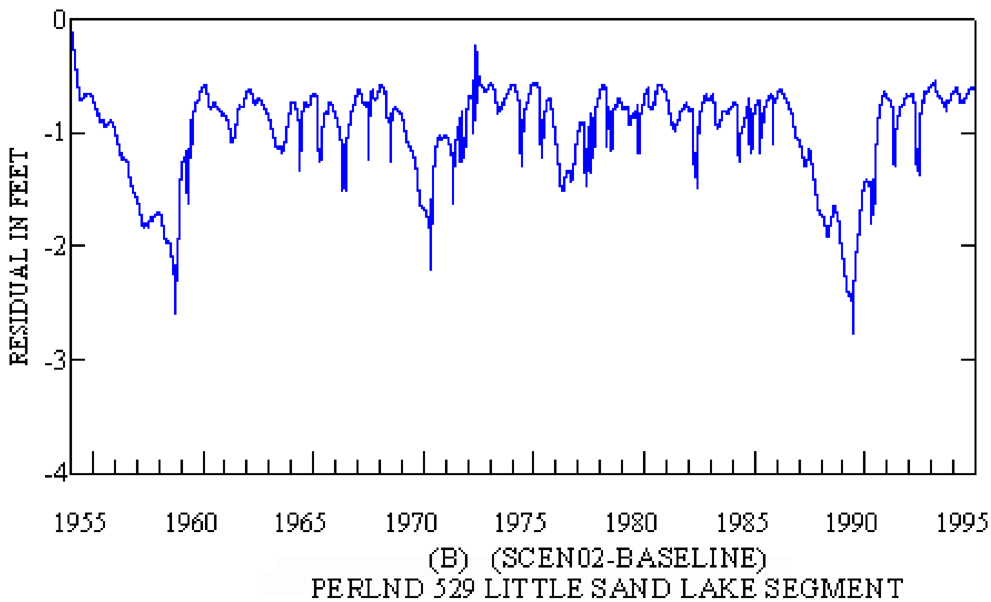


Figure 53. Difference (Residual) in wetland water levels simulated with the Hydrological Simulation Program - Fortran for PERLND 529 (Little Sand Lake) between baseline conditions and (A) Scenario 1, and (B) Scenario 2.

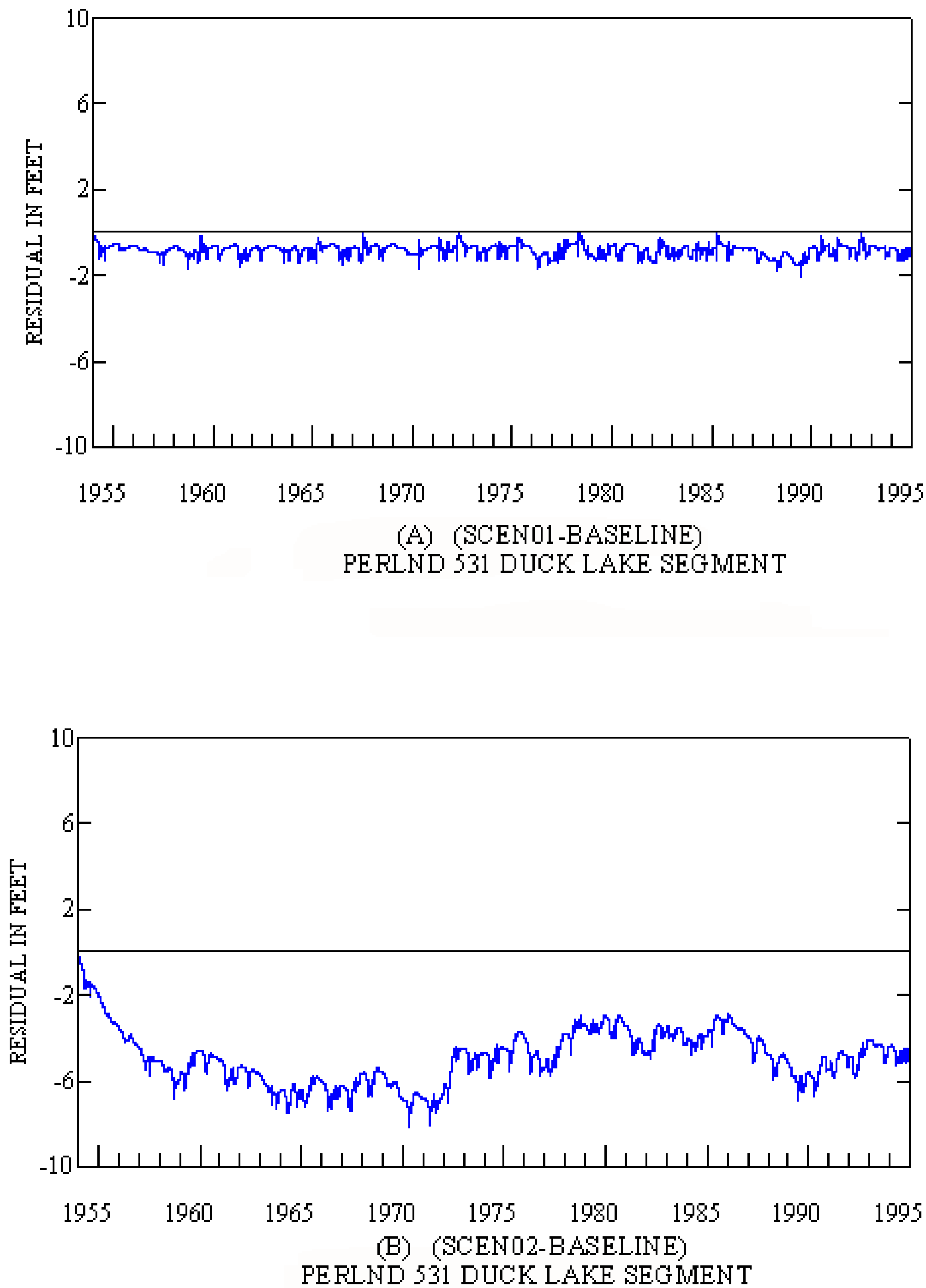
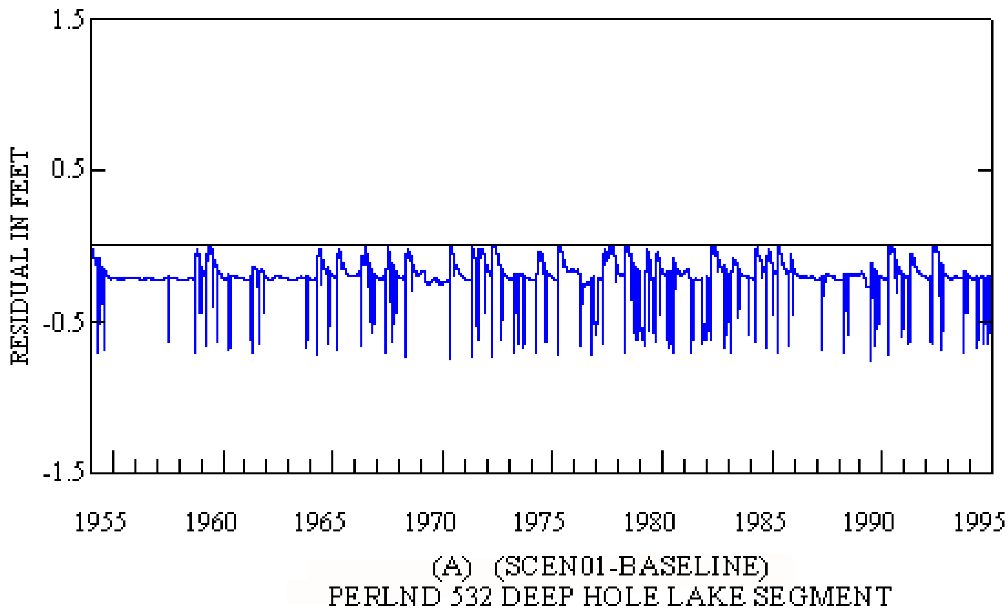


Figure 54. Difference (Residual) in wetland water levels simulated with the Hydrological Simulation Program - Fortran for PERLND 531 (Duck Lake) between baseline conditions and (A) Scenario 1, and (B) Scenario 2.



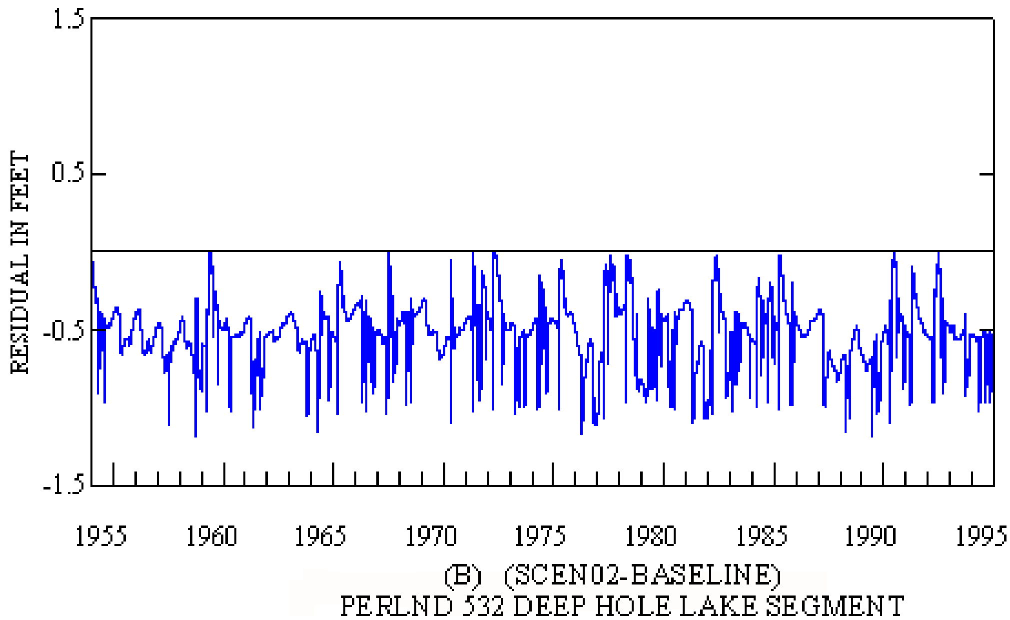
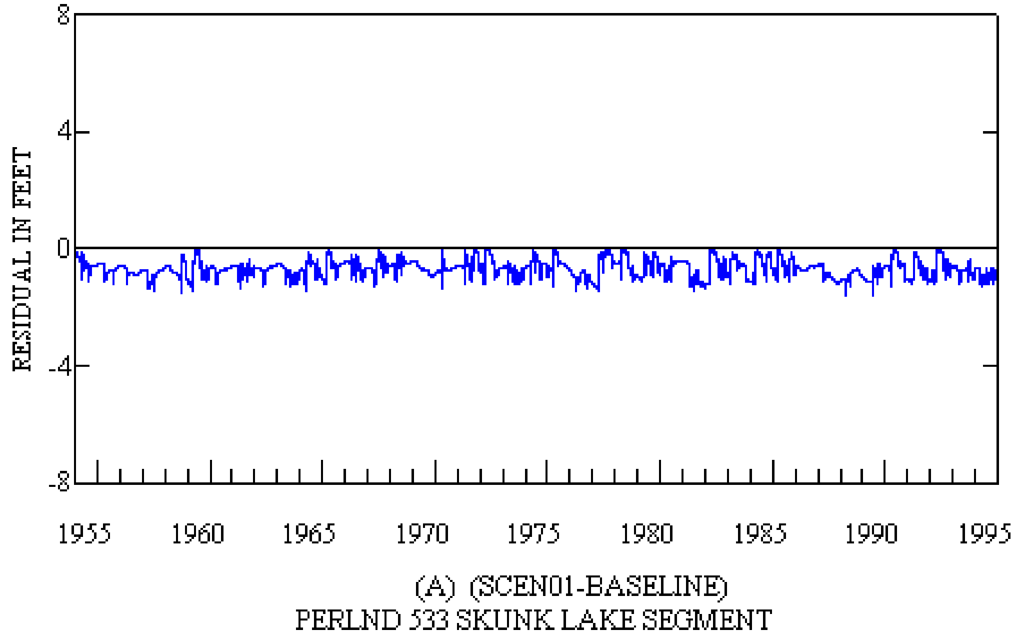


Figure 55. Difference (Residual) in wetland water levels simulated with the Hydrological Simulation Program - Fortran for PERLND 532 (Deep Hole Lake) between baseline conditions and (A) Scenario 1, and (B) Scenario 2.



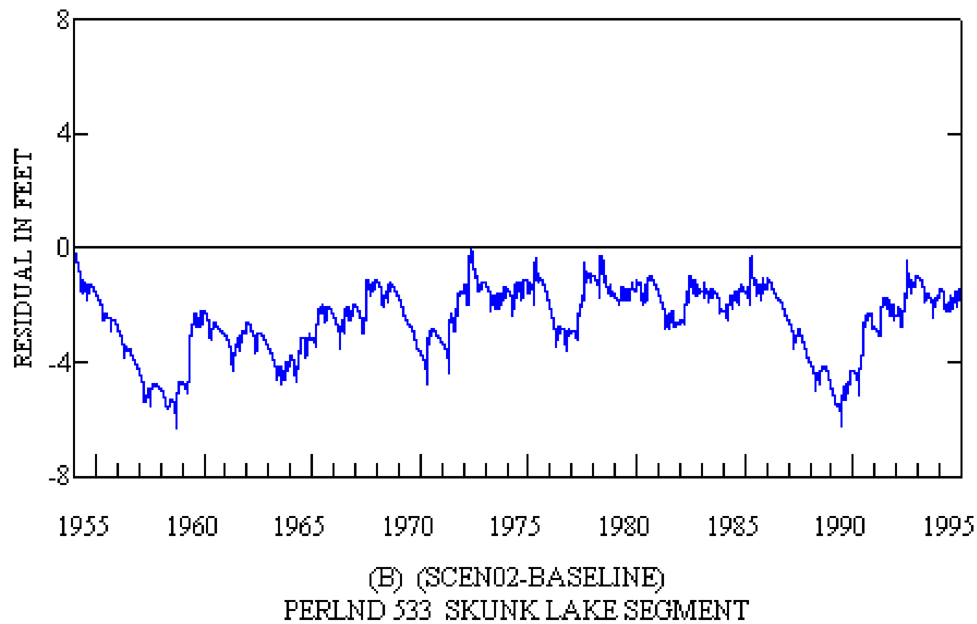


Figure 56. Difference (Residual) in wetland water levels simulated with the Hydrological Simulation Program - Fortran for PERLND 533 (Skunk Lake) between baseline conditions and (A) Scenario 1, and (B) Scenario 2.

LINKING SCENARIO RESULTS TO BIOLOGICAL ASSESSMENT

The optimum use of the HSPF model for this project is to analyze the results for assessing the possible effects of surface water changes on the biota and ecological communities. Toward this goal, the average 41-year conditions and five-year drought periods defined earlier in this report were compiled. In addition, biologists suggested that monthly conditions be compiled individually to assess critical conditions, averaging each month for 41-year average differences, and the entire winter season from October - April. These monthly comparisons between baseline and scenario conditions may be used to help predict changes in species, such as wild rice, or habitat and communities. Average, high, and low flow conditions, stages, fluxes in variability, percentage exceedences, and stream flow duration also are reported. The Swamp and Pickerel Creek watershed data compilation is attached with this report in a CD-ROM format.

SUMMARY AND CONCLUSIONS

The Hydrological Simulation Program - FORTRAN (HSPF) model Version 12 was calibrated using streamflow data collected from 1982-1986 at two locations on Swamp Creek above and below Rice Lake, yielding a correlation coefficient of 0.8828 above Rice Lake and 0.8394 below Rice Lake, and the coefficient of model fit efficiency of 0.6067 above Rice Lake and 0.4447 below Rice Lake for monthly flows. The overall water balance was achieved with - 0.1% and 2.4% error above and below Rice Lake, respectively, when comparing simulation to observed. Temporal verification used data from 1978-1981, and spatial verification was provided by simulation of lake water-surface elevations in the adjacent Pickerel Creek watershed. For monthly flows, the correlation coefficient for verification was 0.8229 above Rice Lake and 0.8346 below Rice Lake, and a coefficient of model fit efficiency was 0.4351 above Rice Lake, (0.6793 when three outlier months were eliminated) and 0.4826 below Rice Lake, but all the other fit criteria remained well within the targets except in one case where the criterion was missed by less than 1%.

A simulation baseline representing natural conditions was then established using a 41-year continuous time-series of meteorological data corresponding to 1955 - 1995. Using the same calibrated parameter set, two scenarios were developed for each of the Swamp Creek and Pickerel Creek watersheds to represent the changes under mining conditions using two different operational pumping rates.

HSPF results show lake water-surface elevation changes for the Swamp Creek watershed to be minimal. This is attributed to the reintroduction of water from the mine into the watershed at the Soil Absorption System.   Furthermore, only a small portion of the capture zone overlaps the Swamp Creek watershed. Therefore, water removed from the Pickerel Creek watershed is effectively transferred to the Swamp Creek watershed. In the Swamp Creek watershed, there is not much change in maximum flow out of the lakes, but minimum and mean flows increase approximately 1 to 3 cfs in the 600 gpm or 1440 gpm scenarios, respectively. Groundwater elevations in wetlands decrease in the segments of the Swamp Creek watershed nearest the plant site and intersecting the capture zone from which groundwater is diverted to the mine in Segments 110, 122, and 140. These decreases at the 600 gpm pumping rate are less than one foot and approximately 1 to 4 feet at the 1440 gpm pumping rate.

Lakes, streams, and wetlands in the Pickerel Creek watershed show greater changes in water-surface elevations, flows, flow duration curves, and wetland water levels than those in the Swamp Creek watershed. The Pickerel Creek watershed water-surface elevation minimum values decrease in all four lakes within the capture zone 1 to 2 feet when comparing the baseline to the 600 gpm pumping rate. Water-surface elevation minimum values decrease in all lakes within the capture zone (except Skunk Lake) approximately 4 feet when comparing the baseline to the 1440 gpm pumping rate. Skunk Lake experiences a 1.5 foot drop in elevation at that pumping rate.

For flows from the lake outlets, all of the minimum values remain the same at zero flow, and the greatest decreases are in maximum flows at Rolling Stone Lake, Duck Lake, and Deep Hole Lake at approximately 4 cfs. Again, this compares the baseline to the 600 gpm pumping rate scenario over the 41-year simulation period. Decreases are 4 to 9 cfs at the 1400 gpm pumping rate scenario. Little Sand Lake and Skunk Lake show very little or no change in maximum flow for either scenario. Rolling Stone Lake outflow decreases because much of its drainage is intersected by the capture zone; this decrease may be attributed to the removal of water from the capture zone in the Pickerel Creek watershed and its transfer to the SAS in the Swamp Creek watershed. When the data are analyzed in drought conditions in the late 1950's and late 1980's, the lake outlet maximum flow values all decrease. For example, the 41-year simulation period Little Sand Lake maintained an equilibrium at maximum flow, but during droughts it drops from nearly 17 cfs to 0.1 cfs in the 1956 -1960 timeframe when comparing baseline to the 1440 gpm pumping rate scenario. At the 600 gpm pumping rate the decrease is smaller, from 17cfs to approximately 12 cfs. Maximum flow values decrease in all lakes from 0.1 to 4 cfs when comparing the baseline to the 600 gpm pumping rate scenario. When comparing the baseline to the 1440 gpm pumping rate scenario, the decrease ranges from 4 to 9 cfs in all lake outlet flows (except Skunk Lake which decreases only 0.2 cfs). The values show similar changes in each lake outflow in the 1987 - 1991 drought.

Flow changes in Creek 12-9 and Little Sand Lake Inlet show maximum flow values decreasing at both pumping rates approximately 6 cfs and 13 cfs, respectively, for the two 41-year scenarios. In drought conditions, both streams decrease in flow approximately 4 cfs for the 600 gpm pumping rate scenario. At the 1440 gpm pumping rate scenario, the Little Sand Lake Inlet experiences a greater overall decrease and greater percentage decrease in flow than Creek 12-9, ranging from a 8 to 14 cfs decrease, and 6 to 8 cfs decrease, respectively. Flow duration curves show that all flows are affected by the scenario conditions, especially in drought years.

Wetland groundwater minimum elevations in pervious land portions of segments intersecting the capture zone experience a 0.2 to 1.2 foot decrease in levels for the Bur Oak Swamp, Little Sand Lake, Duck Lake, Deep Hole Lake, and Skunk Lake segments for the 600 gpm pumping rate scenario. These same areas experience a 0.6 to 2.1 foot drop in minimum wetland water levels for the 1440 gpm pumping rate scenario, and Skunk Lake and Duck Lake segments drop about 5 and 7 feet, respectively. The impact in the ecosystem of any fluctuations or decreases in values in any of the water-surface elevations, lake or stream flows, or wetland levels is to be determined by the bioassessors and/or ecologists.

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